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CONTRIBUTIONS OF RUSSIAN PLANT-INTRODUCTIONS TO THE DEVELOPMENT OF CANADIAN CEREAL CROPS

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INTRODUCTION

In 1900, M. A. Carleton (6) wrote: "For some time there has been a growing inclination among American agriculturists toward the more general use of Russian economic plants, especially of cereals, forage crops and fruits. In some instances the cultivation of Russian cereals has gone on many years without any knowledge, apparently, on the part of the growers that they originally came from Russia."

The same can be said of Canadian agriculturists. Cereal and forage crops, fruits and ornamental plants were and still are being introduced from the Soviet Union into Canada. It is not surprising, therefore, to find, in the literature dealing with economic plants in Canada, numerous references to their Russian origin. These references are widely scattered, and so far no attempt has been made to collect them into a body of knowledge that would allow us to estimate the extent to which Russian plant-introductions have benefited Canadian agriculture. It is the purpose of this study to show how Russian cereal introductions have influenced the development of cereal varieties in Canada.

A study of this nature requires certain definitions, and also a clarification of the difficulties encountered.

Russian plant-introductions are plants coming from territory under Russian sovereignty at the time of introduction, except those varieties that were obtained there, but were known to have originated elsewhere. For example, the oat variety "Swedish Select" was obtained from Russia but originated in Sweden. Also included are varieties which originated in Russia, but were obtained from some other country.

Cereal crops in this study include spring, durum and winter wheat, barley, oats and flax.

"Development of crops" means the mutations, selections and hybridizations which these introductions underwent either in Canada or in some other country prior to their introduction into Canada.

The above definitions are arbitrary and disputable, but they are necessary as a working basis.

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Some of the numerous difficulties which were encountered were:

1. *Mechanism of plant-introductions.* Foreign plants reach Canada through various channels, and no centralized record is being kept of them. Only a dominion-wide survey, with the fullest support of all agencies concerned (Dominion Experimental and Illustration Farms, agricultural colleges and schools, Provincial Departments of Agriculture, commercial seed firms and private growers) would furnish information on past and present plant material.

2. *Lack of records.* In many cases the date of introduction and the exact origin are not known. The use of synonyms, together with incomplete description, make the identification of certain importations an impossible task. Sometimes the name of a variety is the only clue to its origin, while in some instances the names are very misleading.

3. *Lack of crop data.* How many acres were devoted to each variety and what was the total yield of each variety? Figures in this respect are available for only the last decade. The lack of acreage and yield figures for individual varieties makes it impossible to express in quantitative terms the contributions which Russian plant-introductions have made to Canadian economy.

4. *Magnitude of breeding work.* Is it possible to evaluate in qualitative terms the influence of Russian varieties as parent material in breeding work? This study gives a partial answer. The full answer will never be given. Only named varieties are included, while numbered varieties, which constitute the greater part of the breeding work, are omitted.

The only approach, then, which allows a certain amount of precision is a genetical one. The development of cereal crops on a genetical basis can be expressed in genetical terms. The economic interpretation of the results of the breeding work must remain sketchy and vague.

SPRING WHEAT

Spring wheat is indisputably the most important crop produced in Canada. Canada supplies about 40 per cent of all export wheat, and is thus the world's largest exporter of this grain. Table 1 shows the extent of wheat production in Canada.

TABLE 1.—AVERAGE WHEAT AREA, PRODUCTION AND VALUE OF CROP FROM 1937-1941
(From the Canada Year Book 1943/1944)

Crop	Area in acres	Production in bushels	Gross farm value in dollars
Spring wheat	25,065,000	363,586,000	211,743,000
Fall wheat	707,000	19,586,000	14,632,000
All wheat	25,722,000	383,172,000	226,375,000

I. Russian Introductions and Selections from Them

Fife wheats were the only spring wheats imported from Russia that were of any economic importance prior to the establishment of the Dominion Experimental Farms Service and the subsequent systematic introduction of cereal varieties.

A. H. R. Buller (4) gives a detailed account of the origin of Red Fife, mentioning, at the same time, the "elements of romance" which have sprung up around this famous variety. A cargo of wheat was sent from Danzig to Glasgow, and a sample of this grain was sent to the farmer David Fife of the township of Otonabee, Canada West (now Ontario), in 1842. Only one plant from this sample survived giving rise to the variety Red Fife. The exact origin of this variety is, therefore, not definitely known. There is evidence, however, pointing to Russia as source.

Carleton (6), an authority on Russian cereals, wrote: ". . . . the evidence is rather strong that the entire group of Fife wheats, upon which is founded the immense wheat and flour production of the Northwest, came originally from Russia . . ."

C. E. Saunders (4) in 1905, testifying before the parliamentary committee on Agriculture in Ottawa, said: ". . . among our newly-imported European varieties was one under the name of 'Galician'. . . This imported Galician wheat struck me, at once, as being very much like Red Fife . . . They proved to be identical at all stages of their growth as well as when the grain was harvested."

Clark and Bayles (7) state: "That the original seed of Red Fife wheat probably came from Galicia has been established by two other identical introductions, one by the Canadian Department of Agriculture in 1904 and one by the United States Department of Agriculture in the same year."

Galicia was part of Russia in 1842. According to our definition of Russian introductions, Red Fife is a Russian variety.

Red Fife spread very rapidly in Canada and became the principal spring wheat variety for home use and export purposes. It was a heavy yielder and possessed excellent milling and baking qualities. It became famous throughout the world and brought the highest price in the British market. Its greatest drawbacks were late maturity and rust-susceptibility. Since it took 113 to 128 days to mature, it was frequently frozen in the field. The rapid settlement of the prairie regions made the introduction of an early-maturing variety imperative.

II. Hybrids from Russian Parents

"Every promising sort obtainable has been tested under the different climatic conditions existing in Canada, without finding a single earlier-ripening sort in cultivation elsewhere having the high quality and productiveness of the Red Fife" (20). This necessitated cross-breeding experiments at the various Experimental Farms.

"It was on July 19, 1888, when the first experiments were begun in the cross-breeding of wheat on the Experimental Farm (at Ottawa) and since that time several hundred new sorts have been produced and tested" (21). The first object was to combine high quality with earliness. Later trends were to combine both with rust-resistance. Tables 2 and 3 show some of the named hybrids.

A natural cross was suspected between Bobs × Early Red Fife giving Early Triumph and Supreme. These two varieties and Red Bobs 222, a reselection from Early Triumph, were distributed by the University of Alberta and grown in northern Saskatchewan and various regions of Alberta.

TABLE 2.—HYBRIDS FROM THE RUSSIAN PARENTS LADOGA AND ONEGA

Year	Cross	Breeder	Hybrids
1888	Ladoga × Red Fife	Wm. Saunders	A No. 1, Albert, Abundance, Ottawa, Preston Prince, Stanley, Stonewall, Trial.
1888	Ladoga × White Fife	A. P. Saunders	Advance, Alpha, Blenheim, Captor, Carleton, Crown, Huron, Major, Manifold, Percy.
1889	Ladoga × Early Sonora	Wm. Saunders	Vernon
1890	Red Fife × Ladoga	Wm. Saunders	Boyle, Progress
1890	Campbell's White Chaff × Ladoga	Wm. Saunders	Lakefield
1891	Ladoga × Gehun	W. T. Macoun	Bishop
1891	Gehun × Ladoga	W. T. Macoun	Ebert
1891	Gehun × Onega	W. T. Macoun	Harold, Early Riga
1892	Onega × Red Fife	W. T. Macoun	Nixon
—	Yellowfife × Onegafife	C. E. Saunders	Brownie
—	Yellowfife × Onegagehun	C. E. Saunders	482 B

TABLE 3.—HYBRIDS FROM THE RUSSIAN PARENT RED FIFE

Year	Cross	Hybrids
1888	Ladoga × Red Fife	See Table 2
1890	Red Fife × Ladoga	See Table 2
1889	Early Sonora × Red Fife	Angus, Countess, Dawn
1890	Red Fife × Anglo-American	Jordan
1890	Red Fife × Club Bombay	Beauty, Morley
1890	Campbell's White Chaff × Red Fife	Admiral
1892	Hard Red Calcutta × Red Fife	Cassel, Clyde, Markham*
1892	Onega × Red Fife	Nixon
1892	Rideau × Red Fife	Prospect
1892	Red Fife × Campbell's White Chaff	Orleans, Redpath
1892	Red Fife × Gehun	Kingsford, Laurel
1900	Red Fife × Goose	Gatineau
1905	Downy Riga × Red Fife	Ruby, Crown
—	Aurora × Red Fife	Major, Master
—	Red Fife × Hard Red Calcutta	Weldon
—	Red Fife H × Early Red Fife	Piper, Tartan

* Marquis originated from this cross.

The more important hybrids from the above tabulations were: Preston, Red Preston, Stanley, Huron, Percy, Bishop, Early Riga, Downy Riga, and Riga, which were both selected from Early Riga, Ruby, 482 B, Aurore, Markham and Alpha (17).

Early Riga and 482 B were at one time the earliest-ripening varieties grown at the Central Experimental Farm, at Ottawa.

Aurore from Jacinth × Ladoga, was produced in Australia by Wm. Farrer and was introduced into Eastern Canada in 1920. Crosses with Marquis and Garnet failed to show any promise under Canadian conditions.

Ruby is listed here because Red Fife was one parent. Actually this variety goes back to Onega and Gehun:

Onega × Gehun

Early Riga

Downy Riga × Red Fife D Riga M

Ruby

Towards the end of World War I, Ruby was the standard of earliness for Canadian wheat varieties, but was displaced by Garnet.

Preston and Stanley achieved considerable commercial importance, while Huron was less popular (16), except in Eastern Canada where it is still grown to some extent.

The more important selections made from Red Fife were:

Early Red Fife: originated from a single early ripening plant selected out of Red Fife

Red Fife D: one parent of Ruby

Red Fife H or Type Ic: widely grown in the Prairie Provinces, but never a recognized commercial variety

White Connell: an impure strain of White Fife

White Fife: white kernels; was popular in Eastern Ontario and the Maritime Provinces

White Russian: very popular in the Maritimes and still being grown to a limited extent in 1939; a high yielder giving relatively poor flour

Vermillion: a selection from Early Red Fife, but of poor quality

Early Russian: selected from a variety of Russian origin, similar to White Russian, but never of any importance

Monarch, McKendry's Fife, Wellman's Fife, Saskatchewan Fife: named selections from White Russian.

The introduction of Ladoga wheat has been described by Wm. Saunders (21, 22, 23, 24) in great detail. In his search for an early ripening wheat which would escape early fall frosts on the prairies, he turned towards Russia. In the spring of 1887 the first 100 bushels of a variety arrived in Canada. These were obtained at a latitude of 60 degrees, near Lake Ladoga, a latitude equivalent to 600 miles north of Winnipeg. It was 10 to 14 days earlier than Fife wheats and had a similar chemical composition. Wm. Saunders (24) held high hopes for this introduction: "This subject (namely earliness) is of such vast importance for the future of this country that no pains will be spared in the endeavour to ascertain the true bearing of all the facts." In 1903 he wrote (23): "While the idea of growing Ladoga wheat as a competitor with Red Fife for export or the general home trade should be abandoned, there is no doubt that that the flour of the Ladoga makes excellent and nutritious bread for home use." It was difficult to mill and yielded yellow flour. In higher latitudes it thrived much better than at Ottawa, and it was the only wheat which could be grown successfully in the Peace River District (roughly 500 miles northwest from Winnipeg). The most northerly point of cultivation was at Fort

Simpson, 818 miles north of Winnipeg, yielding 62.5 pounds per bushel. Ladoga wheat played an important part in pushing the limit of the settled area northwest, and its earliness made it to an important parent of subsequent hybrids.

Galician Summer, Russian Ghirka (or Red Fife No. 3 as it was called) and Black Sea were Russian introductions of no particular importance. Onega, which came from Archangel, became the hybrid-parent of Early Riga, Harold, Nixon and Brownie. It also became an ancestor of Ruby, Garnet, Pioneer, Crown and Duchess. Onega was a low yielding, but very early variety.

Kota was obtained in Russia by H. L. Bolley, of the North Dakota Agricultural College, in 1903. It was somewhat resistant to stem rust and was, therefore, used as breeding material in Canada, from 1921 on, but never became an important variety commercially.

MARQUIS WHEAT

"The value of this wheat not only to Canadian agriculture but to that of our great Southern neighbour, is almost beyond computation" (4). In 1892, A. P. Saunders crossed Hard Red Calcutta with Red Fife at one of the branch Experimental Farms (C. E. Saunders thinks it was at Agassiz, British Columbia). The progeny from this cross was badly mixed, because Hard Red Calcutta was merely a trade name for a mixture of Indian wheats. In 1903, C. E. Saunders, at the Central Experimental Farm at Ottawa, while selecting from the mixed progeny of the 1892 cross, picked one promising-looking head, which was increased and named Marquis (4, 20). In 1909 it was distributed to the farmers and ten years later it was the leading variety in the North American spring wheat area. In 1923, approximately 90 per cent of the Western Canadian spring wheat land was devoted to Marquis (4).

Marquis replaced Red Fife. It was a heavy yielder, had strong straw and was earlier than the latter. It had excellent milling qualities and gave a flour of remarkable strength.

Kitchener and Renfrew were the most notable selections from Marquis. Some selections carried the name of the person who selected them, e.g. Parker's Selection.

Table 4.—Hybrids from Marquis

Year	Location	Cross	Hybrid	Remarks
1912	Ottawa	Marquis × Prelude	Reward	Gave rise to Regent and Renown
1912	St. Paul	(Marquis × Iumillo) × (Marquis × Kanred)	Thatcher	Released in Canada in 1935
1917	U.S.D.A.	Kanred × Marquis	Reliance	Released in Saskatchewan 1933
1918	N.D. Exp. St.	Kota × Marquis	Ceres	Released by Brandon Exp. St. 1924
1918	St. Paul	Marquis × Kanred	Canus	Selected by O. S. Aamodt, 1929, at University of Alberta
—	Winnipeg	Pentad × Marquis	Coronation	Rust laboratory cross
1927	Saskatoon	(H44-24 × Double Cross) × Marquis	Apex	By J. B. Harrington, University of Sask.

Crosses with Marquis were very numerous and are still being made. The aim is to combine the high quality of Marquis with some other desirable characteristic. Some of the more important crosses are shown in Table 4, and are more fully discussed under "Rust-resistant Varieties."

III. Hybrids with Russian Ancestors

The following varieties can trace their origin back to Russian plant introductions:

Brownie
Chelsea
Chester
Crawford
Dayton
Duchess
Florence
Forward
Fraser
Garnet
Grant
Pioneer
Prelude
Prospector
Producer
Reward
Spence

Alpha, a hybrid from the cross Ladoga × White Fife, became a parent of seven varieties mentioned above, as shown in the following scheme:

Ladoga × White Fife (1888)

Alpha × Hard Red Calcutta (1892) Alpha × Gehun (1892)

Florence Fraser Spence Chester Crawford Grant

Chelsea

Fraser was the only variety achieving any importance in subsequent breeding work. Fraser × Downy Gehun gave rise to Prelude, which in turn gave rise to several other varieties of greater or lesser importance. It was very early, but low yielding.

Ladoga × White Fife (1888)

Alpha × Hard Red Calcutta (1891)

Fraser × Downy Gehun (1903)

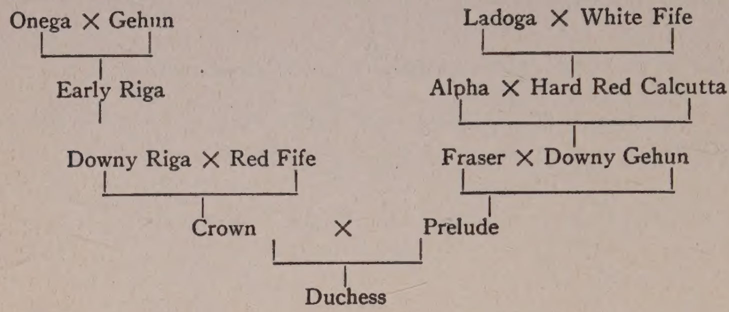
Prelude × Marquis (1912)

Reward

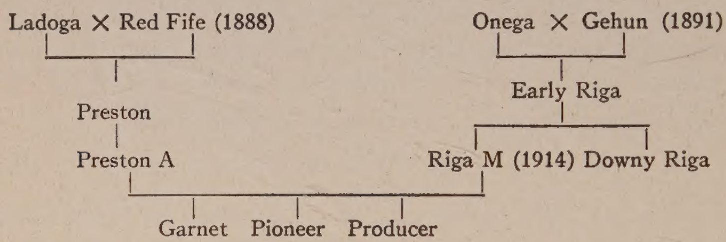
Reward goes back to Ladoga and White Fife. It was one week earlier than Marquis but a poorer yielder. In the Red River valley and in the Northern Park Belt it proved to be of unusually high test weight and quality. However, the yields per acre were disappointing, and the variety was rust-susceptible.

Forward was a mutation of Prelude with high baking strength.

Duchess is a good example of a variety which involved a great amount of breeding work, yet was never commercially grown, and had no outstanding merits.



Garnet: "The history of Garnet wheat is almost an epic in the realm of scientific achievement. It reveals a story of almost half a century of patient, but determined effort, replete with discouragements and disappointments, but rewarded ultimately by definite and indisputable gains" (18). It was extensively grown in Northern Saskatchewan and



Alberta, where earliness and quick maturity are essential. It has only fair milling and baking qualities, being inferior to Marquis, and is rust-susceptible. Since 1935 it has been replaced by rust-resistant varieties, but, at present, is still being grown to a considerable extent in the Peace River District of Alberta and other northern areas.

Pioneer, a sister of Garnet, had good milling and baking qualities, was 10 days earlier than Marquis and Huron, but had a weak straw and was a low yielder.

Producer, another sister-selection, gave remarkable yields at the Dominion Experimental Station Lacombe, Alberta, but was of poor quality.

IV. Rust Resistant Varieties

Nineteen hundred and twenty-two to 1924 was a transitional period in the history of cereal breeding in Canada. C. E. Saunders resigned in 1922 as Dominion Cerealist and was succeeded by L. H. Newman. Two years later the rod-row plot system was introduced, which put the testing of cereal varieties on a sound statistical basis. At the same time the Dominion Rust Laboratory was established in Winnipeg. Its immediate aim was the production of rust-resistant cereal varieties. "Rust-resistance" is a term usually applied to stem rust resistance to prevailing races of *Puccinia graminis* Pers.

Canadian spring wheats received their rust-resistance from Yaroslav emmer.

Yaroslav × Marquis

Reward × H44-24 Hope

Renown Regent × Canus

Redman

(Marquis × Iumillo) × (Marquis × Kanred)

Double Cross Thatcher

(H44-24 × Double Cross) × Marquis

Apex

Apex Selection

Thatcher, Apex, Renown, Regent, Redman, and Saunders[1] are the most important rust-resistant varieties under cultivation at the present time.

American plant-breeders made the first attempts to produce rust-resistant varieties. Their work formed the basis for subsequent breeding work in Canada, which run along three lines: (*a*) interspecific crosses to transfer rust-resistance from the Emmer group (28 chromosomes) to vulgare varieties; (*b*) crosses between resistant hybrids to build up resistance even further, and (*c*) crosses between rust-resistant strains and high quality varieties.

H44-24 was produced by E. S. McFadden in 1916 at Webster, South Dakota, by crossing Yaroslav emmer (*Triticum dicoccum*) with Marquis (*Triticum vulgare*). This cross remained practically immune to stem-rust under field conditions (15). It had mature plant-resistance and became, for this reason, one parent of Apex, Renown and Regent.

Coronation, a hybrid between the durum variety Pentad (*Triticum durum*) and Marquis (*Triticum vulgare*) is now commonly grown in Eastern Canada.

Marquillo, a hybrid between the durum Iumillo, an Italian variety, and Marquis, was produced by H. K. Hayes, at the Minnesota Experimental Station, St. Paul. Marquillo was used in 1925 by Dr. C. H. Goulden in the first six crosses made at the Rust Laboratory at Winnipeg, Manitoba.

Ceres, a hybrid between Kota × Marquis, produced at the North Dakota Experimental Station in 1918, became popular in Manitoba in 1924, but was almost wiped out in the heavy rust epidemic of 1935.

Thatcher originated at the Minnesota Experimental Station in 1921, and was distributed in Canada in 1936. Within two years it occupied 52 per cent of the total wheat acreage in Manitoba, 14 per cent in Saskatchewan, and 1 per cent in Alberta. At present it occupies the greater part of the Western Canadian wheat area, followed by Marquis, Red Bobs, Regent, Renown and Apex.

Apex was released by the University of Saskatchewan in 1937. Marquis entered the parentage four times. Apex Selection is superior to the parent, but is limited almost exclusively to Saskatchewan.

[1] Saunders originated from the cross Brandon Hybrid C-26-44.7 × Thatcher, made at the Central Experimental Farm, Ottawa, in 1938. Brandon Hybrid C-26-44.7 was a selection from the cross Hope × Reward. Saunders, released in 1947, is adapted to Northern Alberta, Northern Saskatchewan and Manitoba.

Regent was developed at the Rust Laboratory at Winnipeg in 1926. It was distributed in 1937 and has replaced Thatcher to a large extent in Manitoba.

Renown, a sister of Regent, never reached the same popularity.

Redman also originated at Winnipeg. It is the most rust-resistant variety available to the Western farmers in 1947. First distributed in 1946, it will, in all likelihood, be very widely grown in Western Canada.

DURUM WHEAT

Durum wheats were, for many years, regarded as inferior spring wheat varieties, until their usefulness for the manufacture of macaroni and spaghetti was recognized. The main reason for their continuous cultivation was rust- and drought-resistance. To-day they are commercially important crops, and are particularly adapted to the Red River Valley (27).

All commercial durum varieties in Canada are of Russian origin.

Russian Introductions

The following varieties were tested by experimental stations in Canada:

Acme	Monad
Arnautka	Nodak
Beloturka	Pererodka
Black Don	Pentad
Gharnovka	Russian Hard Tag
Yellow Gharnovka	Slobodzianka
Goose	Saxonka
Kahla	Taganrog
Kubanka	Velvet Don
Mindum	

Only three of these varieties were commercially important:

Goose, Kubanka, Mindum.

Goose was the most popular durum wheat at the turn of the century. It was identical with Arnautka, and was brought to Canada by immigrants from Russia.

Arnautka was also brought by immigrants.

Kubanka, once the most popular of all durum varieties, was introduced into the United States by M. A. Carleton in 1900, from the Uralsk Government. Two selections became important for Canada:

Kubanka Ottawa 37, a selection from No. 5639, obtained by the Central Experimental Farm at Ottawa in 1909 from the United States Department of Agriculture, became one of the best durum wheats in Canada.

Kubanka Saskatchewan 6 was a selection made from the original United States Department of Agriculture introduction at the University of Saskatchewan.

Mindum was discovered in a field of common wheat, variety Hedgerow, on the Minnesota Experimental Station, St. Paul, in 1896. It was named in 1918. Similar in morphology to Goose or Arnautka, it became the standard durum variety in Western Canada for many years, but is now being displaced by Carleton and Stewart.

WINTER OR FALL WHEAT

"The hard red winter wheats make up the largest and, in many respects, the most important commercial class of wheats in the United States . . . The original seed of hard red winter wheats was introduced from Russia in 1873 . . . The number of distinct varieties . . . has gradually increased from a single variety in 1873 to 34 in 1937" (19).

Almost all of these varieties or hybrids from them found their way to Canada, where they were either grown by farmers or merely tested. Russian-introduced winter wheats in Canada played only a minor part. Other varieties proved to be better adapted and were more widely grown, particularly in Ontario, but in Alberta the Russian introductions became popular. Before spring wheats were grown in Canada, winter wheats played an important part. The latter persisted only where climatic conditions favoured them in Ontario, Alberta and British Columbia. Spring wheats, however, became the leading type of wheat grown for the export trade.

Russian Introductions

In 1873, Mennonites settled for the first time in Kansas. From there they gradually moved northwards, finally reaching Manitoba. Each family brought its own supply of winter wheat seed, known as Crimean. The whole group of Crimean winter wheats was called Turkey. M. A. Carleton's introductions under the names Crimean, Malakof and Kharkof proved to be morphologically identical with it.

This group was grown under various synonyms which, in many instances, are very misleading. The synonyms were: Alberta Red, Argentine, Bulgarian, Crimean, Defiance, Egyptian Hard Winter, Hundred and One, Hungarian, Improved Turkey, Kharkof, Lost Freight, Malakof, Malcome, Minnesota, Red Cross, Pioneer Turkey, Red Russian, Red Winter, Romanella, Russian, Tauranian, Theiss, Turkey Red, Turkish Red, Ulta, Wisconsin 18, World's Champion, Zuni (7).

The following selections were tested in Canada:

Turkey Red 380	Kanred
Nebraska 6, 28, 30, 60	Azima
Karmont	Kharkof M.C. 22
Beloglina	Genesee Giant
Odessa	Siberian
Padui	Alton (Ghirka Winter)

Siberian was a variety grown in Ontario in the middle of the last century, at the time when Red Fife was discovered.

Kharkof M.C. 22, selected at the Macdonald College, Quebec, in 1912 from an introduction which came to Canada in 1904, is being grown in Alberta.

Turkey Red, similar to Kharkof, is also being grown in Alberta.

Ghirka Winter or Alton was introduced into the United States from Russia in 1900 and introduced into Canada in 1910 by the Lethbridge Experimental Station, Alberta. Prior to 1900 a variety of the same name was tested at the Central Experimental Farm at Ottawa.

Hybrids from Russian Introductions

Minhardi	Kanmarqu	Newturk
Minturki	Ridit	Michikof
Tenmarqu	Jones Fife	O.A.C. 104

The above hybrids have Turkey as common parent. They were all produced in the United States, except O.A.C. 104, which is one of the recommended varieties in Ontario at the present time.

BARLEY

"Barley has been grown in Eastern Canada for over three hundred years, and for more than one hundred years in the West. The annual average barley acreage in Canada is approximately three and three-quarter million acres, about three million acres being in the Prairie Provinces" (3). Among cereal crops in Canada, barley occupies the third place. It is either grown for malting or feeding purposes for home and export markets.

"Of the cereal crops grown in Canada, the most inadequately described and the hardest to identify is barley. There are two reasons for this state of affairs; one is the differences between the various types are so obvious that the description of them is almost superfluous, and on the other hand, our cultivated varieties are so closely related that differences between them are difficult to find . . . "(8).

Two rowed barleys were mostly grown in Canada in the latter part of the 19th century because they gave 13 per cent more malt-extract than six-rowed varieties, and were preferred by the British market (25). However, a gradual change took place, whereby six-rowed barleys replaced the older two-rowed varieties, both for feeding and malting purposes, except in the Maritimes where a two-rowed variety is still preferred.

I. Russian Introductions

Baku	Odessa*
Black Russian	Olli*
Caucasian Hulless*	Olonetz
Chousk*	Orel
Dorsett*	Perm
Featherstone	Petschora*
Fleche	Polar*
Golden Queen	Pontiac*
Keystone*	Popeline
Kostroma	Purpesco
Kutais*	Rasput
Lion*	Russian
Luth	Scarab
Mammoth Winter	Silverking*
Mandscheuri*	Sisolsk*
Manchurian*	Stavropol
Mensury (Chinese Ott. 60)*	Taganrog*
Michigan Black Barbless*	Turkestan*
Nerchinsk	Voronetz
O.A.C. 21*	Woodrow

* Mentioned in Canadian references.

Most of these names indicate the place of origin.

Odessa was the only two-rowed variety of Russian origin, but never obtained any importance.

Manchurian barley, also called Mandscheuri, Manchuria, Mensury, Chinese, constituted the most important introduction from Russia. It was introduced by C. A. Zavitz (28), Ontario Agricultural College, who mentions " . . . Mandscheuri which the college imported from Russia in the spring of 1889." In the United States the unpedigreed strains, coming from the Ontario Agricultural College, received the number C.I. 244, while C.I. 241 was given to an introduction of Manchurian barley which a traveller had brought in 1859 from the Amur River District to Germany, whence it reached the Wisconsin Experimental Station at Madison in 1861.

Is Manchuria barley a Russian introduction or is it Chinese? C. E. Saunders, while acknowledging the fact that it came from Russia, nevertheless calls a selection from it Chinese. Historically the Amur River District was ceded to Russia by China in 1859, in which year Manchurian barley reached Germany. It seems possible, though by no means certain, that Manchurian came from Russian-held territory at the time of its introduction, and, therefore, falls under the scope of this study.

O.A.C. 21, a selection from the original Mandscheuri, was released by Zavitz in 1910 and became Canada's leading malting barley for three decades. In Ontario, 95 per cent of the area devoted to barley consisted of O.A.C. 21 and Manchurian, but since 1940, O.A.C. 21 is rapidly losing popularity for two reasons. Montcalm, superior in many respects, is becoming the standard variety, and, secondly, hybrids from crosses involving O.A.C. 21 are replacing the parent.

Keystone, Saskatchewan 228 was selected from O.A.C. 21 and recommended for Saskatchewan in 1922.

Dorsett, selected from Chinese Ottawa 60 (identical with Mensury Ott. 60) never became commercially important.

Pontiac was selected from Mandscheuri at Macdonald College, Quebec.

Odessa was a six-rowed variety reaching Canada from the port of Odessa. There existed also a two-rowed variety under the same name.

Petschora, coming to Canada from the Petschora River, and Polar, from Archangel, latitude 67 degrees, were both introduced by William Saunders in 1887. Both were one week earlier than any other six-rowed variety. William Saunders discovered that both varieties were identical.

Lion is the only Russian introduction comparable to Manchurian in importance. The original plant, six-rowed, black, smooth-awned, was found near Rostov on the Don River, and was sent by the Experimental Station Taganrog to the United States in 1911. Lion became very important in breeding work, introducing smooth awns in hybrids.

Michigan Black Barbless was selected from Lion by F. A. Spragg at the Michigan Experimental Station.

Michigan 31604, a selection similar to Lion, helped to produce Montcalm and Byng.

II. Hybrids Involving Russian Introductions

Most of the commercially grown barley hybrids have as their ancestors Manchurian and Lion. The following tabulation shows in alphabetical order the hybrids grown in Canada:

- Barboff (O.A.C. 21 × Lion)
- Byng (Michigan 31604 × Common 6 rowed M.C.* 4307) × Mensury 32 M.C.*
- Galore (O.A.C. 21 × Lion) × O.A.C. 21
- Glabron (Lion × Manchurian) × Manchurian
- Montcalm (Michigan 31604 × Common 6 rowed M.C.* 4307) × Mandscheuri M.C.* 1807
- Newal (Manchurian × Lion) × O.A.C. 21
- Nobarb (O.A.C. 21 × Lion)
- Prospect (Black Barbless Michigan × Albert)
- Plush (Lion × Bearer)
- Regal (Manchuria × Lion) × Manchuria
- Rex (Velvet × Hannchen) a two-rowed variety
- Sanalta (Smooth Awn × Duckbill)
- Titan (Trebi × Glabron)
- Velvet (Manchuria × Lion) × Luth
- Wisconsin Barbless or Wisconsin Pedigree 38 (Oderbrucker × Lion)

* Macdonald College, Quebec.

O.A.C. 21 is being replaced by Byng, released in 1939, and Montcalm, released in 1945, in Eastern Canada, while Barboff, Galore and Nobarb are doing the same in Central and Western Ontario. The most important varieties in Manitoba at present are: Rex, Sanalta, Plush and Wisconsin Pedigree 38. Regal and Prospect are popular in Saskatchewan, while Newal and Titan are preferred in Alberta.

OATS

"The oat acreage on the North American continent has remained fairly constant during the past few years, fluctuating in Canada between 12 and 16 million acres. The oat crop ranks second in total value among grain crops in Canada as a whole, but in Ontario and other eastern provinces it takes first place by a large margin" (9).

None of the leading varieties came from Russia. However, among the numerous oat varieties grown or tested in Canada are many which were introduced from Russia.

I. Russian Introductions

Black Finnland	Mennonite
Black Tartarian	Poland
Early Archangel	Sixty Day
Eighty Day	Siberian
Green Russian	Tlola
Kherson	Tobolsk
Onega Black	White Russian
Orloff	Zhelanni

Siberian at the Central Experimental Farm at Ottawa was imported in 1888, from a German seed firm, while Siberian at the Ontario Agricultural College was obtained from an English seed firm and was much higher yielding. William Saunders had this to say about these two varieties: "These oats are distinct varieties, and the Guelph seed has thus far been the most productive, but which of them is the true Siberian has not yet been determined" (26).

Kherson and Sixty Day reached the United States from Russia and proved to be very important. In Canada both varieties were tested extensively, but did not become successful commercially. Considerable confusion exists in the nomenclature of selections made from them because several names were given to the same variety.

Eighty Day was a selection from Sixty Day made at Ottawa. It never ripened in 60 days under Canadian conditions.

Orloff closely resembled Sixty Day.

White Russian was of unknown origin with regard to time and source.

White Tartar and Tartarian were identical with White Russian.

Mennonite was grown by Mennonites in Manitoba and was probably brought by them from Russia.

Tobolsk and Zhelanni were sent in 1901 from the United States Department of Agriculture to the Central Experimental Farm, Ottawa.

Tlola was sent from Finland in 1904, at a time when this country belonged to Russia.

Green Russian was grown by the Mennonites of Manitoba and North Dakota. " . . . when or from where it was originally secured is not definitely known . . . It grows more like Kherson . . . is in no way related to the Tartar or Russian group" (5).

Black Tartarian came to Ottawa in 1890 from Scotland. The original source is not known.

II. Selections from Russian Introductions

The selections made from the original introductions became much more important than the parent varieties.

O.A.C. 72, selected from Siberian (Guelph variety), was released in 1911, and in 1915 the college advised the farmers to discontinue Siberian in its favour.

O.A.C. 144, another selection from the same variety, was released in 1923.

Kherson and Sixty Day gave the following popular selections:

Gopher	Iowa 103
Albion	Nebraska 21
Cole	Richland
Iogold	State Pride
Iowar	

Gopher, introduced by the University of Saskatchewan, in 1925 became the standard variety for earliness in Western Canada.

Rainbow, Iogren and Rusota were selections from Green Russian made at the North Dakota and Iowa Experimental Stations.

III. Hybrids from Russian Introductions

TABLE 5.—HYBRIDS FROM RUSSIAN INTRODUCTIONS

Hybrid	Cross	Location	Remarks
Anthony	White Russian × Victory	Minn.[1]	Released 1912; partially stem rust resistant; Manitoba, Southern Saskatchewan.
Exeter	Victory × Rusota	Rust Lab.[2]	Made 1929; rust resistant; North. Manitoba, Eastern Sask.
Lasalle	Siberian 2107 × Joanette 1207 M.C.	M.C.[3]	Quebec only.
Legacy	Banner Ott. 49 × Eighty Day Ott. 42	C.E.F.[4]	Made 1906; Central Saskatchewan, Eastern Alberta, Quebec.
Mabel	O.A.C. 72-214 M.C. × Early Ripe 213 M.C.	M.C.[3]	Leaf rust resistant; Quebec only.

[1] University Farm, St. Paul, Minnesota.
[2] Dominion Laboratory of Plant Pathology, Winnipeg, Manitoba.
[3] Macdonald College, Quebec.
[4] Central Experimental Farm, Ottawa.

Richland, originally known as Iowa 105, selected from Kherson in 1906 by L. C. Burnett, proved to be an important parent in the breeding of disease-resistant varieties.

Victoria, an Australian variety, crossed with Richland at Arlington, Virginia, in 1930, gave the following varieties, which may assume greater importance in Canada in the near future:

Boone	Tama
Cedar	Vicland
Control	Vikota

FLAX

From 90 to 97 per cent of the flax produced in Canada is grown for its seed and not for its fibre. New France in 1720 produced 54,650 pounds of flax seed (14). In 1875, it was grown in Western Canada, and in 1941 approximately 65 per cent of the total western flax acreage was in the Province of Saskatchewan, while 20 per cent was in Manitoba and the remaining 15 per cent is in Alberta, localized in certain areas only (11). The total production of flax in Canada fluctuates widely, reaching the peak of over two million acres and 26 million bushels of seed in 1912. Since 1933 imports became necessary. The second world war increased production greatly, but a decline in output is again noticeable.

H. L. Bolley, at the North Dakota Experimental Station, played an eminent part in the development of a successful flax production in the American Northwest. He turned towards Russia in his search for adapted varieties (2): ". . . the Russian flax areas all lie well within the mean temperature lines which enclose Manitoba, North Dakota, Minnesota, Iowa, Wisconsin and parts of Michigan. For example, the same line of temperature, July 60 degrees and January 0 degrees, pass through Archangel, Viatka and Winnipeg; and the great flax producing areas of each country lie just south of this line."

Bolley introduced large amounts of seed from Russia in 1903. However, a serious problem arose. "All such marketed seed is subject to

mixing at the central shipping points, as for example . . . Riga . . ." Riga, therefore, "does not indicate a variety or strain, but simply that the sample so marked is from the export town Riga, Russia" (2).

In 1913, A. F. Mantle wrote: "The source from which most of the flaxseed grown in Saskatchewan to-day has its rise in Russia" (13). It originated either from Russian introductions made by the North Dakota Experiment Station or was brought by Mennonites from Russia.

I. Russian Introductions

Russian, Common, Riga, Improved Russian and St. Petersburg were similar in appearance and were the first names attached to flax. Russian and Common were brought by Mennonites prior to 1890 (10).

Siberian, Kostroma, Novarossick were tested at the Central Experimental Farm at Ottawa.

Novelty was the name given to Novarossick in 1913.

N.D.R. 52, N.D.R. 73, N.D.R. 114 were selections made by Bolley from Common. The letters stand for North Dakota Resistant, referring to their wilt-resistance. The Experimental Farm at Brandon, Manitoba, introduced these varieties into Canada in 1912.

Bison, also selected by Bolley, was highly wilt-resistant, but rust-susceptible. It was introduced in 1930 and widely grown in Saskatchewan, but is no longer recommended.

Crown, a rust-resistant but wilt-susceptible selection, made at the University of Saskatchewan, is similar to Novelty.

Royal was a rust and wilt-resistant selection from Crown, made at the same university in 1927. Distributed in 1938, it became one of the leading flax varieties.

White Dutch and Blue Blossom Dutch are of Russian origin, and were grown in Holland prior to their introduction into Canada. White Dutch became the source of two important selections which were made at the Minnesota Experiment Station, St. Paul. One was Premost, selected in 1894, very extensively grown at one time, but wilt-susceptible; the other was Redwing distributed in 1912, wilt- and rust-resistant and one of the earlier ripening varieties in Canada.

Damont, Reserve and Newland were selections from Russian N.D. 155, but were never commercially grown in Canada.

Newland, when crossed with the cross (19 × 112 E) produced the variety Renew.

Arrow is the result of the cross Renew × Bison.

Crystal is the result of the cross Bison × Ottawa 770 B, while Koto was produced by crossing (Russian × Argentine) × Bison.

The last three varieties receive particular attention at the present time and may prove to be of commercial importance one day. The origin of other flax varieties in Canada is not sufficiently clear to allow their inclusion here.

DISCUSSION

The geographic, climatic and ecologic similarities between the great plains of the North American continent and of Soviet Russia induced famous plant breeders to turn towards Russia in their search for adapted varieties. William Saunders in Canada, M. A. Carleton, H. L. Bolley and others in the United States, were responsible for the introduction of cereal varieties which formed the foundation for further selections and breeding work.

Mennonites and other immigrants from Russia introduced winter and durum wheats, certain oats and flax varieties, which proved to be particularly suitable for the great plains of this continent.

Hard red spring wheats in Canada owe their earliness to the varieties Ladoga and Onega, their high quality to the variety Red Fife, which presumably came from Russia, and their rust-resistance to H 44-24, which originated from Yaroslav emmer.

Durum and winter wheats are almost entirely of Russian origin.

Russian flax varieties contributed largely to rust- and wilt-resistance in present-day varieties. At one time, all flax grown in Western Canada (the major growing area) was of Russian origin, but recent introductions from other countries decreased their importance. "Nearly all of the fibre flax of the world is grown from seed originating in the region of Pskof, Russia" (12).

Barley in Canada consists to a very large extent of the Manchurian group of varieties which came in 1889 from Russia. Smooth awnedness in barleys was introduced by the variety Lion, which came from Taganrog. Earliness and high quality are also traceable to Russian introductions. Aberg and Wiebe (1) list 20 varieties which have a Canadian accession number. Of these 20 varieties, fourteen trace their origin back to Russian plant introductions.

Oats of Russian origin were not widely grown in Canada. However, they contributed disease-resistance to hybrids which may assume commercial importance in the near future.

High quality, earliness, disease-resistance and smooth-awnedness are the most important contributions which Russian plant introductions have made to Canadian cereal crops. They have helped to push the limits of human settlement northwards, and have also assisted in the establishment of a more permanent and prosperous agriculture in Canada.

SUMMARY

1. References dealing with the introduction of cereal varieties from Russia were collected from widely scattered reports in an attempt to promulgate a basis for the evaluation of these introductions with respect to the improvement of Canadian cereal crops. Famous Canadian and American plant breeders introduced cereal varieties from Russia which were particularly adapted to the great plains region of North America. Many American introductions from Russia found their way eventually to Canada. Immigrants from Russia formed the third source of introduction.

2. Durum and winter wheats grown at present, and flax grown at the turn of the century, were almost entirely of Russian origin. In spring

wheat, earliness, high quality and especially rust-resistance; in barley, earliness, high malting quality and recently smooth-awnedness; in oats and flax, earliness and disease-resistance were the main characteristics derived from Russian-introduced varieties.

3. Earliness of ripening has pushed the limits of human settlement farther north. Disease-resistance, especially rust-resistance, has placed Canadian agriculture on a more permanent and prosperous basis.

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EARLY AND LATE TYPES OF RED CLOVER[1]

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Since the advent of alternate husbandry in Europe, mixtures rather than pure stands of grasses and clovers have been used in meadow and pasture seedings. In earlier times with little, if any, conscious selection of the species used it is reasonable to assume that the mixtures of those days included large numbers of both useful and weed species. However, we know that even later, when the formulation of seed mixtures became a definite practice, large numbers of species were employed with the expectation that they would provide thick and permanent swards and supply abundant and nutritious feed throughout the growing season under any or all conditions of season, soil and management.

In more recent times, it has been shown that such complex mixtures are quite unnecessary and that a properly planned mixing of appropriate strains may well replace the indiscriminate mixing of species where suitable management can be ensured. Much of the earliest evidence in this connection has come from work at the Welsh Plant Breeding Station, where the practice was advocated as early as 1928 (12) and has become part of the advisory policy of the station (2).

This shifting of emphasis from indiscriminate use of species under uncertain management to well-informed selection of species under appropriate management has had a far-reaching influence upon grassland research throughout the world. It has demanded a knowledge of types within species not heretofore available and has provided an impetus to the development of strains adapted to meet special needs. At Macdonald College, interest in strain development has been limited mainly to red clover and timothy, the two species most widely used in seed mixtures in eastern Canada. The present paper is concerned only with red clover.

LITERATURE

Williams (14) at the Welsh Plant Breeding Station was one of the first to make a comprehensive study of types within red clover. He classified all strains of red clover included in his study in three groups, viz. late, early and wild. These groups differed widely not only as regards their botanical characters but also, to an even more marked degree, in respect to their cropping capabilities, persistency and other agronomic characters. The late or single-cut red clovers in the spring and early summer had a more or less dense, tufted and prostrate habit of growth. They tillered freely and although they became more erect as they matured they all retained a spreading habit of growth. Their stems were long, comparatively slender and more or less solid up to the time of flowering, at which time they tended to become fistular. They had also a relatively large number of internodes and side branches. With one or two exceptions, they made comparatively slow growth and flowered only sparingly in the seeding year unless sown early. Before winter set in, they formed dense leafy

[1] Contribution from Faculty of Agriculture, McGill University, Macdonald College, Quebec, Canada. Journal Series No. 240.
[2] Formerly Assistant Professor of Agronomy, Macdonald College, Quebec.

rosettes in which semi-dormant stage they remained until late spring. They were from two to four weeks later than the earlies in starting active growth in the spring and in coming into flower. On this account, they were capable of producing only one full crop annually, the aftermath crop being usually relatively small when the first crop was allowed to flower before it was cut. However, they gave heavy crops of hay and fairly good aftermath crops provided the hay was mown early. Furthermore, they were able to hold the ground well into the second year or possibly the third or fourth on suitable land, and were able to withstand heavy grazing better than the early varieties.

In contrast with this late type, the early or double-cut red clovers had a more erect and open growth, the stems were fewer, shorter, stouter and more fistular, and had fewer internodes and side branches. They were capable of producing two full crops of bloom annually. Although achieving more growth during the seeding year, they were less productive in the first harvest year than the lates. Although differing greatly in respect to their ability to overwinter, none of them was able to hold the ground well into the second year.

The wild red clovers exhibited a much wider variation as regards their morphological and agronomic characters than even the most variable of the cultivated varieties. Generally speaking, they were very small with slender hard stems which were practically solid even when in flower, and much more pubescent than the European strains of commerce. Although they were highly variable in regard to time of flowering, most of them bloomed very early, several weeks before the earliest of the cultivated varieties. In spite of their early flowering habit, however, they did not start active growth as early in the spring as did the cultivated varieties and they produced comparatively little aftermath. They were more persistent than the early clovers. Although less productive in the first harvest year, they were as persistent, though not so productive, as the late clovers in the first two years.

Types of Russian red clovers have been investigated by Lissitzyn and others (6) (7). No sharp demarcation was found between the early and late cultivated types. The late type was generally less leafy, coarser and had longer stems, more internodes and greater winter resistance than the early type. However, wide variation in winter resistance might be found in both early and late types depending on the environments wherein they were developed. Aftermath development might also vary greatly with both early and late types.

A hypothetical classification set forward by these Russian workers was based upon the formation of root rosettes and divided all red clovers into three groups, viz.:

(1) Typical annual, without root rosettes, early flowering, delicate, rare in occurrence.

(2) Not typical perennial, with weakly developed rosettes and little adapted to winter, including both early and late forms.

(3) Typical perennial, with strongly developed rosettes including both early and late forms.

The types of Norwegian red clover have been investigated by Wexelsen (13). Both wild and cultivated forms, as well as hybrids between them, occur in Norway, but much of the red clover commonly found growing wild proved to be cultivated clover. As in Great Britain and the U.S.S.R the true wild red clover bloomed early but more closely resembled the late type in that it was winterhardy and persistent and did not develop flowering stems in the seeding year. It had a more prostrate rosette than the late type and appeared to be slightly more tolerant of low temperature than the hardy late clover, at least in broadcast stands. Both wild and cultivated red clovers showed wide variation in leafiness, pubescence and other flower, leaf and stem characters. In contrast with the well-developed rosettes of late red clover, the early type formed only weak rosettes or none at all. However, in both the early and late types, there was considerable variation in rosette formation and time of blooming. Time of planting or sowing and natural length of day had a marked influence upon the development of rosettes in the planting year. Early planting permitted considerable variation in rosette development whereas late planting reduced the size of the rosettes and the winterhardiness of the plants. There did not appear to be a correlation between first-year growth type and overwintering, but, lacking populations homogeneous for any one growth type the author felt that such a correlation would have been difficult to establish even if it did exist.

Comparison of early and late types of red clover has also received some attention in Sweden where Nilsson (8) drew attention to the fact that the absence of any sharp delimitation between early, medium and late red clover made it difficult to determine genuineness of type in connection with the state sealing of stocks. On account of the variation within individual strains, earliness or lateness could be altered by selection when seed was produced by different techniques, as pointed out by Hellbo (3). The environment of seed production had also to be considered. Strains developed in the more northerly regions, such as Norrland, bloomed rather early in spite of other characteristics common to the late type. However, it has been suggested by Nilsson-Leissner and Nilsson (9) that such strains may have arisen as a result of crossing with the early-blooming wild red clover.

In New Zealand, Levy and Davies (5) classified red clover strains on a basis similar to that used by Williams (14) in Great Britain. Most of the red clover grown in New Zealand was of the broad red or early type and a need was felt for a longer-lived type, such as the English late, which would be more persistent in long rotation pastures and would furnish seed more acceptable on British markets.

In North America, Pieters (10), Pieters and Hollowell (11) and Hollowell (4) recognized as the two main classes of cultivated red clover the early, double-cut and the late, single-cut type. The former is often referred to in America as medium red clover and Pieters (10) has sought to clear up some of the confusion in the literature resulting from the use of this name. Since the early or double-cut type is the one more widely grown, the number of late, single-cut varieties reaching commercial channels have been restricted to an unimproved variety commonly known as Mammoth and an improved variety of Canadian origin named Altaswede.

Hollowell (4), however, drew a further distinction between agronomic forms of the early and late type based upon pubescence and origin. He recognized four general groups, viz.: American double-cut, European double-cut, American single-cut and European single-cut. Although seeds of these were indistinguishable, the plants of each might be recognized readily if grown to maturity. The late-maturing double-cuts were, however, somewhat similar to early-maturing single-cuts. Investigations of hundreds of lots from varieties of both domestic and European origin had shown that in populations of European origin over 90 per cent of the plants had appressed pubescence. Without critical inspection they appeared glabrous, but upon closer scrutiny they were seen to have a few trichomes or hairs. On the other hand, populations of plants from domestic sources generally had less than 10 per cent of plants with such pubescence and were classified as rough pubescent. Since American red clover came originally from Europe it had been suggested that the rough pubescent character was due to the survival of segregates of this type within populations subject to attacks of the potato leafhopper, *Empoasca fabae.*

RED CLOVER TYPES IN EASTERN CANADA

The early or double-cut type of red clover is the one most commonly grown in eastern Canada. It is represented by numerous strains resulting from long-continued importation of foreign stocks from diverse sources. It varies in winter-hardiness in accordance with the origin of the seed. However, in spite of a great diversity in origin of the stocks they show a similar and rather restricted range of growth types. This may be due, in part, to the seed production methods commonly followed. In localities where seed is produced, the first (hay) cutting is made during the latter part of June and the second (seed) cutting about two and one-half months later. Thus seed production is restricted to those plants which soon produce a second crop of flowering stems following the hay cutting. Any tendency on the part of the seed grower to delay the first cutting in order to secure larger yields of hay or to work under weather and other conditions more favourable for curing serves to intensify the selection, all the slowly developing late-flowering plants being eliminated from seed production.

Toward the northern limits of the region where red clover is grown in Canada, a short growing season interferes with the practice of taking two cuttings from red clover in one season. It is here that strains of the late type are well adapted. They include regional strains of mammoth red clover or kindred sorts. There is also a considerable acreage of Altaswede, a strain particularly adapted to conditions in northern Alberta. Where red clover of this late type is grown in southern districts of Ontario or Quebec, it is mainly as a seed production enterprise and the acreage is quite limited. With this type of clover, seed is saved from the first, and only, bloom of the season. This seed production practice tends to maintain within the strain a somewhat greater range of types than is found in commercial strains of early red clover. One result of this is a wider range in time of blooming of the plants within a population which in turn tends to make these late strains more unstable than early ones under different seed production techniques and natural factors influencing pollination.

Pollinating insects which vary in their numbers and activity during different periods of summer may have a chance of being more effective when the blooming period of a strain is of long duration than when it is short.

Still another result of this greater range in type found in late red clover is a more variable growth habit shown by plants in their seeding or planting year. Under eastern Canadian conditions, the ordinary commercial red clover of the early type regularly shows rather weak rosette development (Figure 1). Coupled with this, it has a strong tendency to produce flowering stems. On the other hand, late strains show a wider range in rosette development with a relatively weak tendency to produce flowering stems. As pointed out by Lissitzyn (6), red clover strains which have a strong rosette development with few flowering stems have little opportunity of reproducing themselves by seed during the seeding year. However, this may be of little practical importance in Canada, due to local conditions which usually do not allow the plants to reach the seed stage in the seeding year. It seems to the writer of much greater significance that the early development of late red clover is decidedly vegetative in nature and that its vegetative phase is of much longer duration than in commercial red clover of the early type. Whether this long and pronounced vegetative phase is associated with the greater winterhardiness or longevity commonly attributed to late red clover may depend largely upon the conditions under which a strain is developed and the importance of the various factors influencing winterhardiness or longevity under those conditions. It is to be expected that differences in winterhardiness and longevity between early and late types of red clover will vary greatly from place to place and that longevity may or may not be determined by winterhardiness. It would not seem reasonable to attribute to growth habit a difference in winterhardiness between early and late red clover without some knowledge of the natural selection to which each had been exposed. For example, a strain of late red clover developed under mild winter conditions with natural selective factors for winterhardiness weak or inoperative would not be expected to exceed in hardiness a strain of early red clover developed under a rigorous winter climate. When measuring the influence of growth habit upon winterhardiness it is therefore important to use strains developed under similar environmental conditions.

Such material became available at Macdonald College in recent years during the selection of improved strains of early and late red clover from similar foundation material which had become well adapted locally and, although predominantly early, contained a wide range of growth habit types.

GROWTH HABIT AND WINTER SURVIVAL

The influence of growth habit on the winter survival of early and late selections as well as the original foundation material is shown in Table 1. The seedling plants were transplanted to the field in early summer and spaced 30 inches by 30 inches apart. Growth habit data were collected in October and winter survival the following May. The basis for grading plants according to growth habit was rosette development and the production of stems as illustrated in Figure 1. Those which had large, leafy rosettes and either no stems or only one or two non-flowering stems were

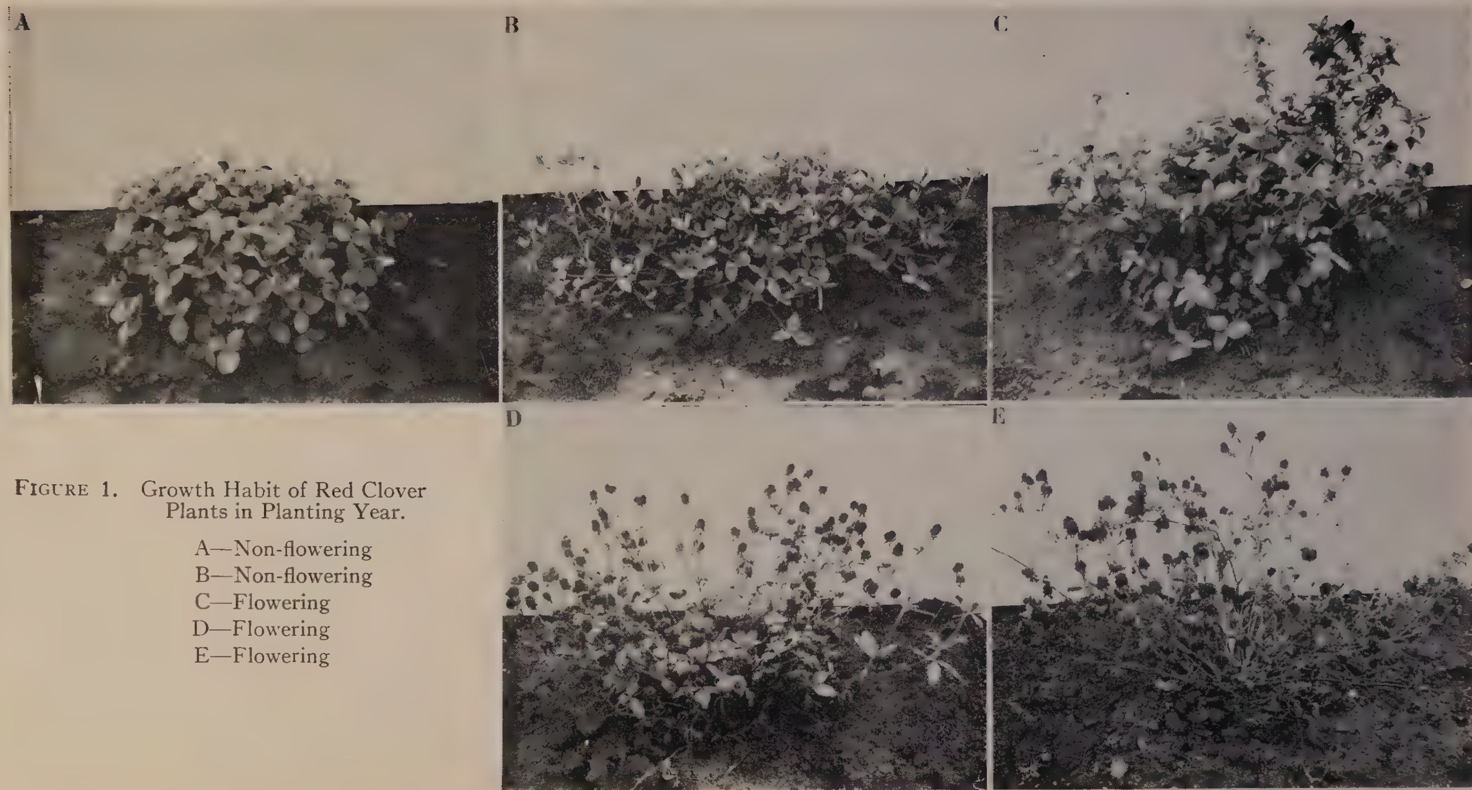

FIGURE 1. Growth Habit of Red Clover Plants in Planting Year.

A—Non-flowering
B—Non-flowering
C—Flowering
D—Flowering
E—Flowering

FIGURE 2. Mature Growth of Red Clover
Left—Early Type *Right*—Late Type

classified as non-flowering, while those which had a medium large rosette, a weak rosette or none at all and which had few to many flowering stems were classified as flowering plants.

From the winter survival of plants within each class, the percentage survival has been calculated. Since the foundation material was grown during an earlier period than the selections while the early and late selections were grown in separate blocks, it is not proper to make a direct comparison between these different types of material without due allowance for these facts.

It will be noted that the total survival of plants has varied greatly from year to year with the severity of the winters. The stage of development reached by the various plantings has also varied to some extent and may have had some influence on the overwintering condition of the plants. In the majority of years the non-flowering plants have shown the greater percentage survival, although in some years the difference is quite small and may have little or no significance. A grand total of 15,134 non-flowering plants had a percentage survival of 62, whereas 16,598 flowering plants had a percentage survival of 43. The late selections have shown a higher percentage of total survival than the early selections although the figures are not directly comparable, due to the fact that the different selection types were grown in separate blocks for spacial isolation purposes. The fact that the numbers of plants set out varied considerably from year to year and that there were unequal numbers in the different classes must also be taken into account in comparisons of figures for years with one another and with the general averages for different types of material. The general trend of these results, however, seems to suggest that, under the conditions which prevail at Macdonald College, seedling habit of growth and winter survival of red clover are definitely related and that the non-flowering plants such as those which predominate in late strains have, in the planting year, a better chance for winter survival than those which flower vigorously.

YIELDS OF EARLY AND LATE RED CLOVER

On account of a longer period of vegetative growth in the harvest year, late red clover does not reach its maximum development until from ten days to two weeks later than the early type. During this longer period, it grows taller and branches more freely than early red clover, as shown in Figure 2, resulting in a first cutting which provides a high yield and which constitutes a high percentage of the total seasonal yield due to limitations placed upon the aftermath by late cutting.

The names double-cut and single-cut often applied to early and late red clover, respectively, do not fully do justice to these contrasting types. They have reference to hay cutting made at or about the full bloom stage and give no consideration to the aftermaths which follow, and, though low in yield, provide feed which is leafy, palatable and of high feeding value in proportion to its bulk. As pointed out by Aamodt, Torrie and Smith (1), in a season favourable for two cuttings from the mammoth type, it may produce as large a seasonal yield as the early red clover. At Macdonald College, an attempt has been made to obtain a fairer comparison between early and late red clover than is possible by the use of hay cuttings alone.

TABLE 1.—INFLUENCE OF GROWTH HABIT ON WINTER SURVIVAL OF RED CLOVER IN SPACED PLANTINGS

Material	Year	Growth habit classes			Winter survival			Percentage survival		
		Non-flowering plants	Flowering plants	Total plants	Non-flowering plants	Flowering plants	Total plants	Non-flowering	Flowering	Total
								%	%	%
Foundation material	1931-32	1362	425	1787	453	73	526	33	17	29
	1932-33	139	564	703	36	0	36	26	0	5
	1933-34	231	801	1032	123	175	298	53	22	29
	1934-35	182	1409	1591	62	223	285	34	16	18
	Total	1914	3199	5113	674	471	1145	35	15	22
Early selections	1937-38	214	1474	1688	202	1213	1415	94	82	84
	1938-39	67	1306	1373	44	581	625	66	44	45
	1939-40	1044	1033	2077	694	505	1199	66	49	58
	1940-41	478	1718	2196	446	1495	1941	93	87	88
	1941-42	97	998	1095	10	42	52	10	4	5
	1942-43	165	1773	1938	159	1644	1803	96	93	93
	1945-46	115	3313	3428	13	28	41	11	1	1
	Total	2180	11615	13795	1568	5508	7076	72	47	51
Late selections	1937-38	1218	831	2049	1088	745	1833	89	90	89
	1938-39	721	127	848	515	81	596	71	64	70
	1939-40	1711	29	1740	1280	14	1294	75	48	74
	1940-41	711	34	745	653	23	676	92	68	91
	1941-42	1902	20	1922	66	0	66	3	0	3
	1942-43	1695	224	1919	1647	215	1862	97	96	97
	1943-44	523	177	700	195	39	234	37	22	33
	1944-45	1673	29	1702	1423	21	1444	85	72	85
	1945-46	886	313	1199	237	36	273	27	11	23
	Total	11040	1784	12824	7104	1174	8278	64	66	64
Total	1931-46	15134	16598	31732	9346	7153	16499	62	43	52

TABLE 2.—COMPARATIVE YIELDS OF STRAINS OF EARLY AND LATE RED CLOVER FROM DIFFERENT CUTTINGS AND PERCENTAGE OF TOTAL DRY YIELD AT EACH CUTTING, ALSO TOTAL OF ALL CUTTINGS, FIVE-YEAR RESULTS

Strains	Date of cutting					Percentage of total yield at each cutting					Actual dry yield in tons per acre from each cutting					Mean 5 yr.
	1940	1941	1942	1944	1945	1940	1941	1942	1944	1945	1940	1941	1942	1944	1945	
Early type:																
Dollard																
1st cut	24/6	12/6	16/6	27/6	26/6	59	83	86	71	64	2.20	2.06	2.77	2.50	2.60	2.43
2nd cut	14/8	29/7	3/8	3/8	1/8	39	11	11	27	19	1.45	0.27	0.35	0.95	0.78	0.76
3rd cut	11/9	12/9	4/9	5/9	10/9	2	6	3	2	17	0.08	0.15	0.10	0.07	0.69	0.21
Total	—	—	—	—	—	—	—	—	—	—	3.73	2.48	3.22	3.52	4.07	3.40
Quebec Comm.																
1st cut	21/6	9/6	12/6	27/6	22/6	61	80	87	71	63	1.64	1.66	2.44	1.67	1.74	1.83
2nd cut	9/8	21/7	27/7	3/8	1/8	36	12	11	27	23	0.97	0.25	0.31	0.64	0.63	0.56
3rd cut	11/9	12/9	4/9	5/9	10/9	3	8	2	2	14	0.08	0.16	0.05	0.05	0.39	0.15
Total	—	—	—	—	—	—	—	—	—	—	2.69	2.07	2.80	2.36	2.76	2.54
Late type:																
Late M.C.																
1st cut	10/7	3/7	29/6	5/7	11/7	72	92	87	83	75	2.44	1.90	3.02	3.02	2.94	2.66
2nd cut	11/9	12/9	4/9	5/9	10/9	28	8	13	17	25	0.95	0.17	0.46	0.62	0.98	0.64
Total	—	—	—	—	—	—	—	—	—	—	3.39	2.07	3.48	3.64	3.92	3.30
Altaswede																
1st cut	10/7	3/7	29/6	5/7	11/7	83	96	98	96	90	2.53	2.01	2.97	2.68	2.65	2.57
2nd cut	11/9	12/9	4/9	5/9	10/9	17	4	2	4	10	0.52	0.08	0.06	0.11	0.29	0.21
Total	—	—	—	—	—	—	—	—	—	—	3.05	2.09	3.03	2.79	2.94	2.78

Differences for significance at 5% point for total seasonal yields in 1940, 1941, 1942, 1944 and 1945 were 0.26, 0.21, 0.33, 0.19 and 0.47 tons per acre, respectively.

In addition to the single cutting of the late strains and the two cuttings of the earlies, all made at the full bloom stage, the aftermaths following these cuttings have been harvested from all plots in early September, as shown in Table 2. Thus the early strains have been cut three times and the late ones twice. In Table 2 will be found the comparative dry yields over a five-year period of two early and two late strains together with the percentage of the total dry yield obtained at each cutting. The Dollard and Late M.C. strains were developed at Macdonald College by combining early and late selections, respectively. These are the selections referred to in Table 1, and as mentioned above they were derived from the same foundation material and therefore had been exposed to the same natural selection agencies. On this account, it is considered that a comparison of the yields of these two strains measured the influence on yield, if any, of factors associated with time of blooming and growth habit independent of factors associated with natural selection in diverse environments which may be of importance in the case of the other two strains.

While on the basis of the first cutting, the early strains may appear somewhat inferior, their rapid recovery and larger second cutting compensates for this and the mean seasonal yield of the two types are similar. As would be expected, their comparative yields vary considerably from year to year with seasonal conditions. While the final cutting of the early strains in some years may be almost negligible in comparison with their total yields, those of the late strains and particularly such well-adapted ones as Late M.C. may be quite important and should certainly be taken into account in any comparison of strains. Under the conditions which prevail at Macdonald College it would seem that there is very little difference in the yielding ability of well-adapted strains of early and late red clover.

PROTEIN CONTENT

No true evaluation of early and late red clover can be based upon yield alone. The prolonged vegetative growth of the late type resulting in taller, coarser stems with marked tendency to lodge produces a hay of lower feeding value than that of the early type when both are cut at the full bloom stage of maturity. This lower quality of the hay is reflected in figures for percentage of crude protein of samples from the 1940 and 1945 crops of the four strains compared in Table 2. These are shown in Table 3.

TABLE 3.—MEAN PERCENTAGE OF CRUDE PROTEIN* OF CUTTINGS FROM TWO EARLY AND TWO LATE STRAINS IN 1940 AND 1945

Strains	First cutting	August cutting	September cutting
	%	%	%
Early type:			
Dollard	16.9	20.1	27.7
Quebec Comm.	17.7	19.8	24.8
Late type:			
Late M.C.	15.0	—	23.1
Altaswede	14.9	—	19.8

First and August cuttings made at full bloom stage.
* Crude protein calculated from nitrogen determinations made by Chemistry Department, Macdonald College.

From the standpoints of both yield and feeding value it would seem advisable to cut late red clover at a slightly earlier stage of maturity than is the custom for early red clover. By cutting the late clover a week earlier than full bloom, a hay equal in feeding value to early red clover might be obtained at little or no sacrifice in total seasonal yield.

SUMMARY

The formulation of seed mixtures under present day conditions demands a thorough knowledge not only of species but also of types within species. Red clover is the most commonly seeded legume hay in eastern Canada and a study has been made of types within this species from material which became available during a strain development program. Special attention has been paid to growth habit in the planting year and its influence upon winter survival, comparative dry yields of plots at different cuttings and their total seasonal yields, and the crude protein content of the cuttings.

The predominant growth habit shown by spaced plants of late red clover in the planting year, with well developed leafy rosettes, appeared to increase winter survival over that shown by early red clover, with its stemmy growth, under these conditions. Although late red clover gave higher hay yields than the early type when cut at the full bloom stage the total seasonal yields from well-adapted strains were similar. The crude protein content of late red clover cut at the full bloom stage was slightly lower than that of early red clover cut at the same stage.

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MALLING STOCKS AND FRENCH CRAB SEEDLINGS AS STOCKS FOR FIVE VARIETIES OF APPLES. IV.

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In the fall of 1947 it became advisable, as a result of crowded conditions, to remove the second half of the fillers in the Malling rootstock orchard at the Horticultural Experiment Station at Vineland Station, Ontario. To bring the records up to date, the tree sizes, yields, and their variabilities have been calculated and analysed as they were in the fall of 1947, the end of the eighteenth year in the orchard. The third report on this orchard was made in the fall of 1942 (4), when all trees on Malling II roots, except in the Melba variety, were removed. In 1947 all trees on Malling I and the balance on Malling II were taken out. Except in the combinations where one or more trees died, each stock-scion combination consisted of 14 trees.

RESULTS

Mortality

There have been few losses among the trees in this orchard (Table 1). Two R.I. Greening trees on Malling I broke off at the union and the other one died from crown or root injury, which was also the cause of death of a total of three trees on French Crab seedlings. One Melba on Malling II did not start in the first summer and the other one died from crown or root injury. No trees on Malling XVI root have died from any cause, a point in favour of this rootstock.

TABLE 1.—MORTALITY AMONG TREES OF EACH STOCK-SCION COMBINATION AFTER 18 YEARS IN THE ORCHARD*

	French Crab	XVI	I	II
R.I. Greening	0	0	3	—
Melba	—	—	0	2
Delicious	0	0	0	—
Spy	1	0	0	—
McIntosh	2	0	0	—

* Fourteen trees of each combination.

Trunk Size

In area of cross-section of trunk French Crab seedlings hold a non-significant lead over Malling XVI in three of the four varieties (Figures 1 to 4)—no change in the past five years. Trees on Malling I are falling behind the other two rootstocks with respect to size of trunk. They are now, on the average, about two-thirds the size of the trees on French Crab seedling roots. In the Melba variety, the only comparison, Malling II trees have trunks about 16 per cent larger than those of Malling I trees—a significant difference (Figure 9).

[1] Chief in Research.

Yield of Fruit

In three varieties the trees on French Crab seedlings have an insignificant lead in yield of fruit over the Malling XVI trees, but in McIntosh the order is reversed (Figures 5 to 8). The per-tree yields on Malling I were appreciably less than those of the other two rootstocks but not always of statistical significance. However, on the basis of a fixed area of trunk cross-section, the Malling I trees lead in three varieties out of four (Table 2). On this basis Melba on Malling I seems to be slightly more productive than Melba on Malling II. Similarly, except in the McIntosh variety, the French Crab seedling trees were more productive than the Malling XVI trees.

TABLE 2.—YIELD OF FRUIT (KGM.) PER 100 SQ. CM. OF TRUNK CROSS-SECTION (INCLUDING THE EIGHTEENTH YEAR)

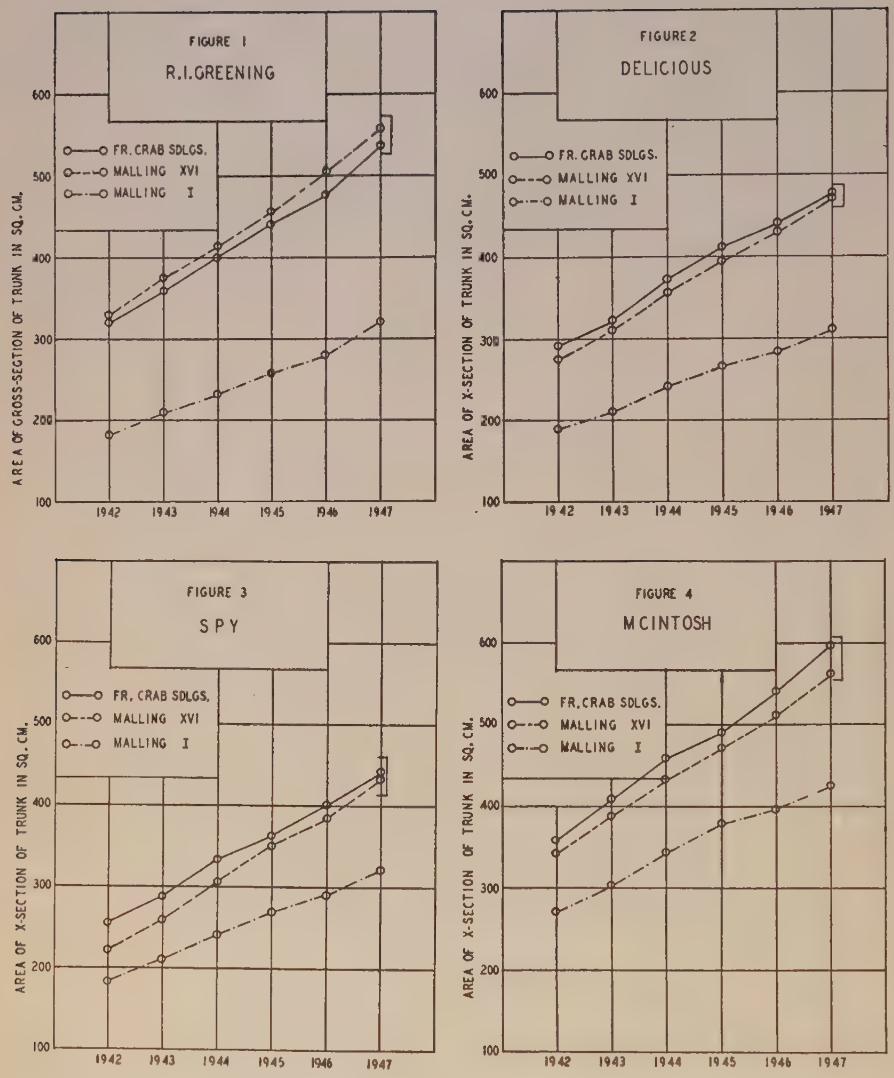
	French Crab	XVI	I	II
R.I. Greening	178	166	215	—
Melba	—	—	212	191
Delicious	136	133	103	—
Spy	103	70	136	—
McIntosh	213	262	270	—

Grade of Fruit

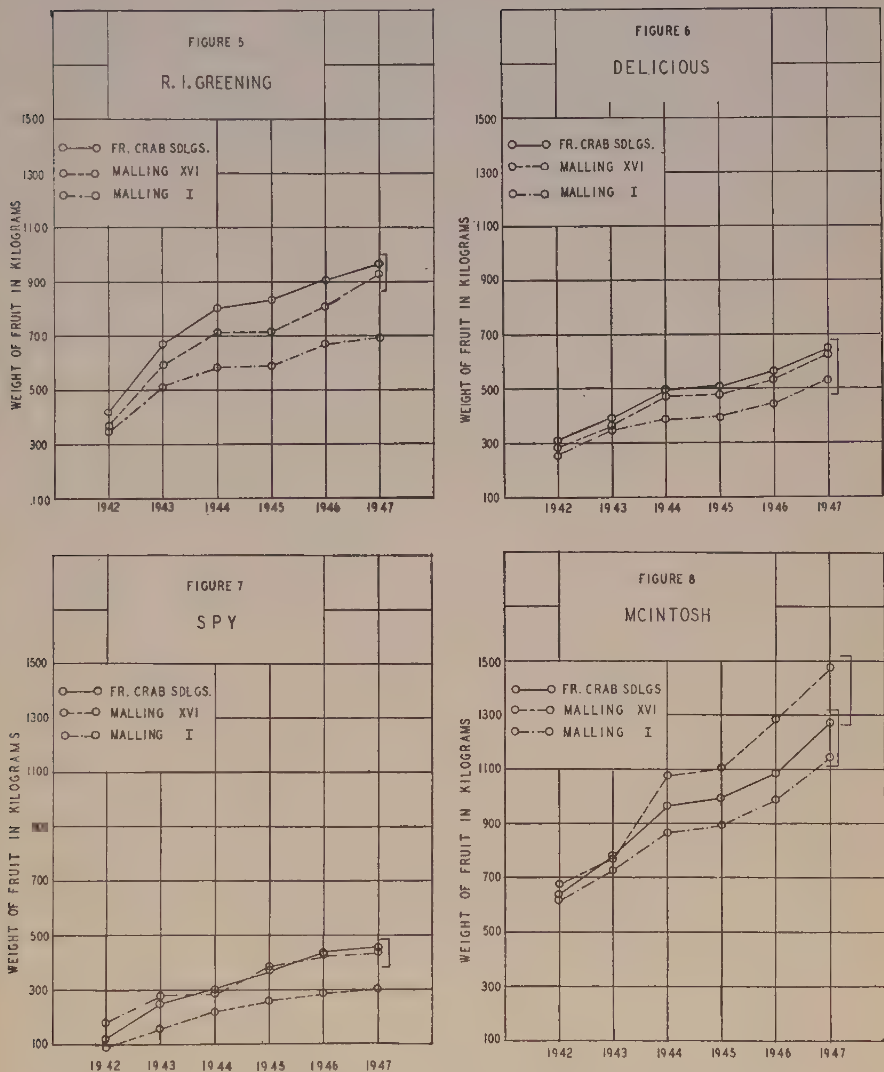
One bushel of fruit from each tree, or the whole crop if less than this quantity, was graded each year. Unfortunately three of the varieties on French Crab seedlings were not of the same colour strain as the trees on the Malling rootstocks. The Delicious and Spy strains on French Crab seedlings were inferior in colour, and the McIntosh, superior. Having these differences in mind it would appear that, with the exception of McIntosh, the trees on French Crab seedlings gave as good or better grade than the trees on Malling XVI (Table 3). Also, with the exception of McIntosh, Malling I trees had as good or better grade of fruit than Malling XVI trees. In this orchard the McIntosh apples borne on Malling XVI trees were noticeably superior in colour, which largely accounts for their good grading record. There was no difference in grade of fruit between Melba on Malling I and Melba on Malling II.

TABLE 3.—NO. 1 APPLES AS PERCENTAGES OF THE TOTAL SAMPLE, AVERAGES FOR THE CROPS OF 1937 TO 1947, INCLUSIVE

	French Crab	XVI	I	II
	%	%	%	%
R.I. Greening	71	61	74	—
Melba	—	—	27	27
Delicious	64	75	75	—
Spy	40	39	47	—
McIntosh	66	74	60	—



FIGURES 1 to 4. Mean area of cross-section of trunk, 1942-47. The 1947 averages bracketed together were not significantly different.



FIGURES 5 to 8. Accumulated yields of fruit per tree, 1942-47. The accumulated yields within a bracket were not significantly different in 1947.

Size of Fruit

All four varieties have had a slightly higher proportion of the fruits above 7 cm. (largest size-class) on the Malling XVI rootstocks than on the French Crab seedling rootstocks. In R.I. Greening, Delicious, and Spy the size difference could be associated with the smaller crops per unit of trunk cross-section on Malling XVI, but not so for McIntosh, where productivity has been greater (Table 2). As in grade of fruit, McIntosh on Malling XVI has been a good combination with respect to size of fruit. In all varieties the fruits from Malling I trees were smaller than those from French Crab seedling and Malling XVI trees. Between Malling I and II in the Melba variety there was no appreciable difference.

TABLE 4.—APPLES ABOVE 7 CM. IN DIAMETER AS PERCENTAGES OF THE TOTAL SAMPLE, AVERAGES FOR THE CROPS OF 1937 TO 1947, INCLUSIVE

	French Crab	XVI	I	II
	%	%	%	%
R.I. Greening	73	77	72	—
Melba	—	—	25	24
Delicious	62	67	51	—
Spy	80	82	73	—
McIntosh	57	64	55	—

Variability

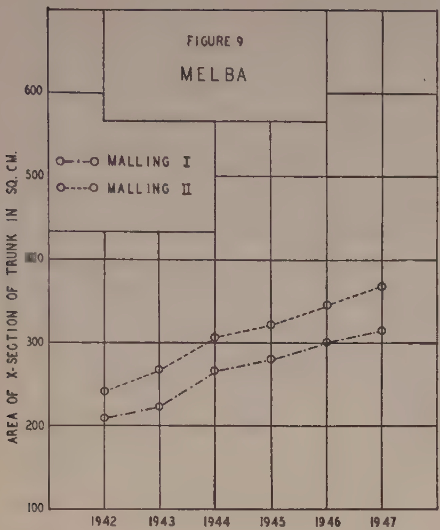
Since 1942 there has been a general tendency for the trees in this orchard to become slightly less variable in both trunk measurements and yield (Table 5). In size, Malling I trees still show the greatest variability and, as before, the variability in yield is much greater than in area of cross-section of trunk. In both trunk growth and yield three varieties were more variable on the clonal Malling XVI than on French Crab seedlings. Only in McIntosh was it the opposite way. In this variety the trees on Malling XVI were outstanding in their uniformity of tree size and fruit yield.

TABLE 5.—COEFFICIENTS OF VARIABILITY IN 1942 AND 1947, MEAN OF FOUR VARIETIES

	French Crab	XVI	I
Area of cross-section of trunk 1942	15	16	23
Area of cross-section of trunk 1947	15	14	21
Accumulated yield to 1942	35	31	32
Accumulated yield to 1947	28	26	29

Malling IX

The trees on Malling IX were also removed in the fall of 1947. At that time it was found that two of the four McIntosh trees were scion-rooted. Another one of this combination had been knocked over by a truck in 1946. With these eliminations, the trees were so few in number that the data might prove to be misleading. Suffice it to say that the non-scion-rooted trees on this rootstock were still growing and fruiting well at the end of the eighteenth year in the orchard.



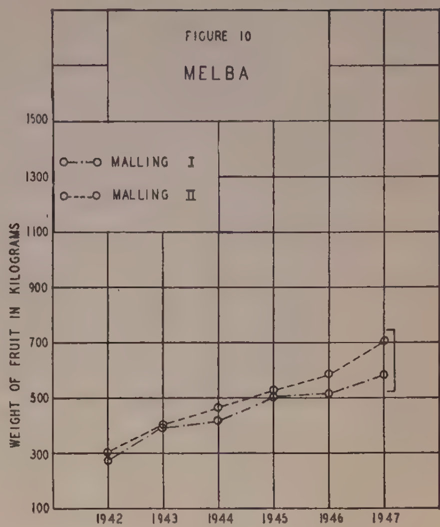


FIGURE 9. Mean area of cross-section of trunk, 1942-47.

FIGURE 10. Accumulated yields of fruit per tree, 1942-47. The bracket indicates that the accumulated yields were not significantly different in 1947.

DISCUSSION

Trees on the clonal Malling XVI and Malling I rootstocks have proven to be just as variable, or more so, in growth and production as trees on French Crab seedlings. One must look therefore to other reasons for using them. Of the five varieties in the orchard only McIntosh looked markedly superior on Malling XVI. On this root the trees were very uniform, in both growth and yield, and were very productive for their size, bearing fruits of good size and superior colour. In Massachusetts (2) McIntosh on Malling XVI has been a good combination.

Malling I cannot be recommended for R.I. Greening and Delicious owing to possible breakage at the union and poor anchorage (4), respectively. It has not been favourably received in either Pennsylvania (1) or West Virginia (3). In the Vineland tests it seems to have some merit for Melba, Spy and McIntosh, where a somewhat smaller than standard tree is wanted. However, because of its behaviour with some other scion varieties the trees should not be planted in windy locations, and then only as small trial plantings.

SUMMARY

Five varieties, R.I. Greening, Melba, Delicious, Spy, and McIntosh, propagated on French Crab seedlings, Malling XVI, I, II and IX were planted in the fall of 1929. Except for the Melba variety, all trees on Malling II were removed in 1942. This report on the orchard brings the results together for the period up to the end of the eighteenth year with the following conclusions:

1. There was some mortality of trees on all rootstocks except Malling XVI.

2. There were no significant differences in trunk measurements between trees on French Crab seedlings and Malling XVI. The trees on Malling I averaged about two-thirds the size of the trees on French Crab seedlings.

3. Except for the McIntosh variety, the trees on French Crab seedlings were more productive than the trees on Malling XVI. With Delicious excepted, the trees on Malling I were more productive for their size (trunk) than the trees on French Crab seedlings.

4. The differences in grade and size of fruit due to rootstock influence were of minor degree. Trees on Malling I, all varieties, had a lower proportion of the largest size-class than the trees on the other two rootstocks. McIntosh on Malling XVI was outstanding in its size and colour of fruit.

5. There was no evidence of greater uniformity of growth or yield by the use of the clonal Malling rootstocks except for the one combination, McIntosh on Malling XVI. In this orchard the coefficient of variability for yield was much greater than for trunk cross-sectional area.

6. In the Melba variety, Malling I trees were smaller, more productive for their size, and showed less mortality than Malling II trees.

ACKNOWLEDGMENT

The author wishes to express his thanks to J. A. Thompson for preparing the graphs used in this paper.

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THE STANDARD ERRORS OF DIFFERENT DESIGNS OF FIELD EXPERIMENTS AT THE UNIVERSITY OF SASKATCHEWAN[1]

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The use of randomized designs in field plot experimentation was commenced, according to Garner and Weil (8), in 1925 at the Rothamsted Experiment Station. In 1926, R. A. Fisher (7), in his first paper on field experimental designs, emphasized the importance of randomized arrangements in the estimation of experimental error and described the randomized block and latin square designs. A year later these designs were adopted for use in the cereal variety trials at the University of Saskatchewan at Saskatoon. During the ensuing twenty years, other designs including various lattices were also used. The purposes of the present paper are to study the distribution of percentage standard errors of different designs and to compare the designs for their efficiency.

MATERIAL AND METHODS

The analyses of 523 tests as recorded in the Annual Reports[3] of the Cereal Breeding Investigations at the University of Saskatchewan for the years 1925 to 1946, inclusive, were used for this study. Of the 523 tests, 483 were carried out at Saskatoon and the remaining 40 at breeding nurseries at Tisdale and Bladworth and the Dominion Experimental Stations at Indian Head, Melfort and Swift Current.[4]

Systematically arranged rod row plots were used during the period 1925 through 1929 with a total of 39 experiments. Commencing in 1927 randomized block designs were used extensively until 1946, the total being 126. Latin squares also were adopted in 1927 and by 1946 a total of 123 had been used. These consisted of 1 (7×7), 91 (6×6), 9 (5×5), 9 (4×4) and 13 (3×3) squares. The use of split-plot latin squares began in 1936 with 14 designs devoted to wheat, 2 to barley and 1 to oats. The main plot arrangement of 11 of these tests was a 4×4 square and of the remaining 6 it was a 6×6 square. Split-plot randomized block designs were used for two wheat and two barley cultural experiments. Semi-latin squares (also known as modified latin squares) were used in 133 experiments during the years 1933 to 1944. There were two (2×2), 46 (3×3), 48 (4×4), 12 (5×5), 21 (6×6) and 2 (7×7) squares. Lattices and incomplete block designs were first used at Saskatoon in 1937. During the ten years 1937 to 1946 the following lattice design experiments were run: 15 simple, 22 triple, 7 quadruple, 1 sextuple, 1 rectangular, 10 balanced, 22 lattice squares and 3 balanced incomplete block designs, the total being 81.

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[2] Research Fellow and Professor of Field Husbandry, respectively.

[3] Typewritten reports filed at the University and reproduced in part in mimeographed form every two years.

[4] Saskatoon is on the gently rolling open plains of Central Saskatchewan and has a heavy textured soil on a silty glacial lake deposit. The soil is known as Elstow silty clay loam. The annual precipitation for a 37-year period averaged 13.8 inches with a range of 8.8 inches to 21.0 inches. The soil at Swift Current, Bladworth, Indian Head and Tisdale varies from medium textured brown clay loam through dark brown to degraded black clay loam and the annual precipitation averages from 14 to 17 inches.

TABLE 1.—DESCRIPTION OF MICROPLOTS USED IN THE YIELD TRIALS AT SASKATOON

Plot symbols	Number of rows per plot	Distance in inches between		Plot length in feet	Rows harvested		Area of plot cut in sq. feet
		Rows	Plots		Number	Length in feet	
E	3	12	12	18.5	1	16.5	16.50
EE	1	18	18	18.5	1	16.5	24.75
K	1	12	12	18.5	1	16.5	16.50
N	3	6	12	18.5	2*cs*	16.5	20.63
P	4	9	9	18.5	2*c*	16.5	24.75
Q	3	6	12	11.5	3	10.0	20.00
T	5	6	12	11.5	3*c*	10.0	15.00
Y	4	12	12	11.5	2*c*	10.0	20.00
I*	2	6	24	8.0	2	8.0	20.00
G†	5	6	24	8.0	5	8.0	32.00

c—Centre row or rows; *cs*—centre row and one side row; *—used only for beans; †—used only for peas.

Various sizes and shapes of plots have been used in the Saskatoon trials. As early as 1911, Mercer and Hall (11) working with mangolds showed that the size of individual plots influenced the magnitude of the experimental error. Garner and Weil (8) classified standard errors per plot into three groups according to the size of plots used, the largest standard error being for the smallest or microplots. The Saskatoon tests were all made with small plots excepting in 1927 and 1928 when 13 systematically arranged tests were made with 1/20 and 1/40 acre plots. The microplots used varied from 15 to 32 square feet of harvested crop. The details on the various kinds of plots used are given in Table 1.

The E, P, T, and Y plots are all small plot types in which competition and border effects are reduced to a minimum by having the border rows and row ends omitted from the portion of the plot harvested for yield. The T and Y plots are the latest types being used here. They furnish individual plots which closely represent miniature farmers' fields for note-taking purposes. The N type plot is one in which competition is partially eliminated with two of the three rows harvested. The remaining row of the plot is left standing for use in late note-taking as are the border rows of the E, P, T and Y type plots. With the K, EE and Q type plots, all the rows are harvested except for the portion at each end of the rows which is left to remove border effect. These types of plots are used for preliminary testing where the amount of seed is very limited.

The results of statistical analysis of these experiments were recorded in the original summarizations and also in the Annual Reports. One of the statistical figures tabulated is the standard error of a single plot yield of each experiment. This standard error of a single plot yield, when it is expressed in percentage of the mean yield of all of the plots in each experiment, is called the percentage standard error per plot and is used for a ready comparison of the accuracy of the experiments.

The standard errors of the 523 experiments were collected and calculated by expressing them in percentage of their corresponding means. Then the frequency distributions of these standard errors were classified according to crops, designs and size of the error. The average percentage

TABLE 2.—DISTRIBUTION OF STANDARD ERRORS PER PLOT BY SIZE GROUPS FOR SIX CROPS

Crop	Type of design	Distribution of percentage standard errors								
		0.0 to 4.0	4.1 to 8.0	8.1 to 12.0	12.1 to 16.0	16.1 to 20.0	20.1 to 24.0	24.1 to 28.0	Over 28.0	Total tests
Wheat	Rn. Block	—	11	14	24	8	3	2	5	67
	Lat. Square	1	22	17	11	6	6	2	1	66
	Semi-Lat. Sq.	—	3	12	13	10	2	2	2	44
	Lattices	—	7	14	13	2	1	—	—	37
	Sp.pl.L.S. (m)	—	2	1	2	2	—	2	5	14
	Sp.pl.L.S. (s)	—	6	6	2	—	—	—	—	14
Barley	Ran. Block	—	2	—	5	2	—	2	—	11
	Lat. Square	—	—	5	5	4	—	—	—	14
	Semi-Lat. Sq.	—	6	10	11	9	3	3	3	45
	Lattices	—	1	6	2	3	—	—	—	12
	Sp.pl.L.S. (m)	—	—	1	—	—	—	—	1	2
	Sp.pl.L.S. (s)	—	—	1	1	—	—	—	—	2
Oats	Ran. Block	—	—	4	5	1	1	—	—	11
	Lat. Square	—	2	7	1	—	—	—	—	10
	Semi-Lat. Sq.	—	4	14	7	8	4	1	1	39
	Lattices	—	1	12	—	3	—	—	—	16
	Sp.pl.L.S. (m)	—	—	—	—	1	—	—	—	1
	Sp.pl.L.S. (s)	—	—	1	—	—	—	—	—	1
Flax	Ran. Block	—	2	5	6	4	4	—	—	21
	Lat. Square	—	3	2	3	4	—	—	—	12
	Lattices	1	2	3	6	2	1	1	—	16
	Semi-Lat. Sq.	—	—	—	—	1	—	—	—	1
Rye	Ran. Block	—	—	5	2	3	2	1	1	14
	Lat. Square	—	—	3	2	—	1	—	—	6
	Semi-L. Sq.	—	—	—	2	1	—	—	—	3
Peas and beans	Ran. Block	—	—	1	—	—	—	1	—	2
	Lat. Square	—	2	6	6	1	—	—	—	15
	Semi-L. Sq.	—	—	—	1	—	—	—	—	1

Note.—Two split-plot randomized block experiments on wheat, and another two on barley are not shown in this table.
Ran. Block = Randomized Block; Lat. Square = Latin Square.
Semi-Lat. Sq. = Semi-Latin Square; Sp.pl.L.S. = Split-plot Latin Square.
(m) = Main plot; (s) = sub-plot.

standard error per plot of each design for the different crops, and the relative efficiency ratios for comparing the accuracy of different designs were calculated by methods described by Yates (17).

Throughout the years the best methods of designing tests have been placed in use at Saskatoon as they were brought into notice by statisticians. There has been a gradual evolution of testing procedure with considerable "overlapping" of designs but no direct comparisons of designs on the basis of either duplicated tests or uniformity data. As the present study includes hundreds of tests run on various crops over a period of 22 years, all relevant factors were fully considered before an attempt was made to study the standard errors and the comparative merits of the designs used. These factors include the soil, date of sowing, type of plot used, favourableness of season, and number of varieties per test. Data on the last two of these appeared to be sufficiently important to be included in the results.

TABLE 3.—SUMMARIZED DISTRIBUTION OF STANDARD ERROR PER PLOT ACCORDING TO TYPE OF DESIGN USED

Standard errors in per cent	Randomized blocks	Latin-squares	Semi-latin-squares	Lattices	Split-plot latin-squares		Total*
					Main	Sub	
0.0 – 4.0	—	1	—	1	—	—	2
4.1 – 8.0	15	29	13	11	2	6	68
8.1 – 12.0	29	40	36	35	2	8	140
12.1 – 16.0	42	28	34	21	2	3	125
16.1 – 20.0	18	15	29	10	3	—	72
20.1 – 24.0	10	7	9	2	—	—	28
24.1 – 28.0	6	2	6	1	2	—	15
28.1 – 32.0	3	1	4	—	—	—	8
32.1 – 36.0	3	—	2	—	1	—	5
Over	—	—	—	—	5	—	—
Total	126	123	133	81	17	17	463
Mean % S.E.	14.76	11.98	14.87	11.88	23.95	9.88	13.55

* Excluding the standard errors of the split-plot latin-squares.

TABLE 4.—DISTRIBUTION OF AVERAGE PERCENTAGE STANDARD ERRORS PER PLOT ACCORDING TO FAVOURABLENESS OF SEASON AS SHOWN BY WHEAT YIELDS

Experimental designs	Distribution of standard errors			
	Unfavourable	Mod. favourable	Very favourable	Average
Randomized block	15.74 (14)	15.24 (59)	13.64 (53)	14.62 (126)
Latin Square	14·27 (7)	12·29 (55)	11·45 (61)	11·99 (123)
Semi-latin square	18.61 (36)	12.98 (82)	15.45 (15)	14.78 (133)
Lattices	12.81 (19)	12.20 (40)	10.98 (22)	12.01 (81)

( ) Bracketed figures denote number of tests.

RESULTS

Distribution of Standard Errors

The distribution of the percentage standard errors per plot, according to magnitude for the different designs is given in Table 2 for each of the crops. The bulk of the wheat tests have been made with randomized blocks and latin squares whereas with oats and barley semi-latin squares have predominated. In recent years lattice designs have been used almost exclusively for all of the crops.

In Table 3 the distribution of the standard errors is consolidated to facilitate comparisons between designs. The distribution for the latin squares is quite similar to that for the lattice designs. The distributions for randomized blocks and semi-latin squares also are closely alike. In the split-plot latin squares the main plot errors are larger and have a larger range than the sub-plot errors.

TABLE 5.—DISTRIBUTION OF AVERAGE PERCENTAGE STANDARD ERRORS PER PLOT ACCORDING TO NUMBER OF VARIETIES IN THE TESTS

Experimental designs	Distribution of standard errors			
	Below 11	11 to 20	21 to 40	Above 40
Randomized block	13.45 (54) *6.2*	15.42 (36) *15.4*	15.35 (24) *28.6*	16.07 (12) *61.4*
Latin-square	11.99 (123) *5.5*			
Semi-Latin square	10.98 (10) *8.6*	14.15 (51) *15.6*	15.48 (64) *29.0*	17.93 (8) *50.2*
Lattices		10.36 (10) *16.0*	12.12 (53) *26.5*	12.60 (18) *60.2*

Note.—Bracketed figures denote number of tests. Italicized figures indicate the average number of varieties per test.

Some Factors Affecting the Size of the Standard Errors

Before different designs were considered for the sensitivity of varietal comparisons, the size of the standard error was studied in relation to the favourableness of the season and the number of varieties in a test.

At Saskatoon, as at most stations located in the drier part of the Great Plains Region, there are tremendous differences in the favourableness of different seasons for crop production. Plot yields of wheat on summer-fallow at Saskatoon have varied from an average of 10 bushels per acre in 1937 to 62 bushels in 1942. In Table 4 the distribution of the standard error per plot of the different kinds of tests is given according to the favourableness of the season as indicated by the average yields of wheat. The average percentage of standard errors for randomized blocks was: 15.7 for 14 tests made in unfavourable (dry) seasons; 15.2 for 59 tests made in moderately favourable seasons; 13.6 for 53 tests made in very favourable seasons. The trend of the distributions for the other designs was similar to that of the randomized blocks in that it was toward smaller percentage standard errors with more favourable growing conditions. The percentage standard errors with very favourable conditions averaged lower (about 16 per cent) than those for tests grown in unfavourable seasons.

The standard error tended to increase with an increased number of varieties in a test as shown in Table 5. The increase for randomized blocks was from 13.4 to 15.4 for below 11 and for 11 to 20 varieties, respectively; with larger numbers of varieties there was little further increase. The latin square and the semi-latin square were more efficient than randomized blocks for below 11 varieties. The double local control of the semi-latin square seemed to add little to its efficiency when more than a few varieties were concerned. The lattice designs showed distinctly greater efficiency than the randomized blocks or semi-latin squares either for a small or a large number of varieties.

TABLE 6.—AVERAGE PERCENTAGE STANDARD ERRORS PER PLOT OF RANDOMIZED BLOCKS AND LATIN-SQUARES FOR DIFFERENT CROPS

Designs	Wheat	Barley	Oats	Rye	Flax	Beans	Peas	Weighted mean
Rand. Block	14.18 (67)	15.46 (11)	13.40 (11)	16.21 (14)	14.86 (21)	18.04 (2)	—	14.62 (126)*
Latin-square	11.74 (66)	13.71 (14)	9.86 (10)	13.51 (6)	12.75 (12)	14.87(2)	10.05 (10)	11.99 (123)
Relative efficiency	68.6	78.7	54.1	69.4	73.6	67.9	—	67.2

* These mean values are calculated from the ungrouped data. The figures within the parenthesis in the above table indicate the number of experiments from which the average percentage is calculated.

Randomized Blocks and Latin Squares

Randomized blocks and latin squares were both used extensively during the period 1927 to 1946 and the data afford a good comparison of the two types of tests. The average percentage standard errors for these designs are shown in Table 6. In all of the crops the standard errors of the latin squares are smaller than those of the randomized blocks. The two types of designs may be compared for their relative efficiency, calculated as the ratio of the squares of the mean errors as elucidated by Yates (17) in 1935. The randomized block arrangement on the average proved to be only 69 per cent as efficient as the latin square for wheat, 79 per cent for barley, 54 per cent for oats, 69 per cent for rye, 74 per cent for flax and 68 per cent for beans. The average efficiency of randomized blocks was 67 per cent that of the latin squares.

The foregoing efficiency percentages do not present a fair comparison, because the average number of varieties per test for randomized blocks is 18.4 and for latin squares 5.5. With an approximately equal number of varieties (6.2 for R.B. and 5.5 for L.S.), the average standard error for 54 tests of randomized blocks was 13.4 per cent (Table 5) and for 123 tests of latin squares it was 12.0 per cent. The average efficiency of randomized blocks was thus raised to 79 per cent of that of the latin squares.

The Saskatchewan results are in accord with those obtained elsewhere. Yates (17), studying data obtained on sugar beets and potatoes at Rothamsted, found the efficiency of the randomized block to be 60 per cent and 55 per cent, respectively. Cochran (3), using Rothamsted data on field experiments, found the error mean squares of randomized blocks and latin squares to be 60 per cent and 45 per cent as high, respectively, as of completely randomized experiments. Garner and Weil (8), also using Rothamsted data, obtained similar results.

Split-plot Latin Squares, Split-plot Randomized Blocks and Semi-Latin Squares

Before the introduction of the lattices and balanced incomplete block designs three other types of designs were used, two of them extensively, for the Saskatoon, Bladworth and Tisdale tests. One of these is the split-plot latin square described and discussed fully by Yates (17, 21, 22). The other is the semi, or modified, latin square introduced by "Student" according to Hunter (13) and discussed by Snedecor (12) and Yates (22). The statistical

TABLE 7.—RELATIVE EFFICIENCY RATIOS OF SPLIT-PLOT LATIN-SQUARE EXPERIMENTS

p = 4					p = 6				
k	r	r_m	r_s	r_b	k	r	r_m	r_s	r_b
2	1.33	1.16	0.88	1.02	3	5.79	2.40	0.42	1.08
2	2.31	1.48	0.64	1.06	3	5.95	2.42	0.41	1.08
4	7.04	3.19	0.45	1.09	3	7.71	2.59	0.34	1.09
6	2.48	2.08	0.84	1.04	3	3.36	1.98	0.59	1.05
7	0.92	0.93	1.01	1.00*	3	2.12	1.60	0.75	1.03
7	24.68	6.80	0.28	1.21*	4	20.29	3.91	0.19	1.12*
7	6.06	3.88	0.64	1.11					
8	19.68	7.01	0.36	1.19*	Mean	4.99	2.20	0.50	1.07
10	6.91	4.75	0.69	1.09					
12	4.50	3.68	0.82	1.05					
12	1.33	1.30	0.98	1.01					
Mean	4.00	2.69	0.74	1.06	Mean	4.38	2.50	0.65	1.06

* This is not used for calculating mean values.
p = the side of latin-square, k = the number of sub-plots per main plot.
r = Relative efficiency of layout for sub-plot to main-plot treatments.
r_m = Relative efficiency of complete randomization within blocks to actual layout for main plot treatments.
r_s = Relative efficiency of complete randomization within block to actual layout for sub-plot treatments.
r_b = Relative efficiency of complete randomization within block to actual layout for comparison between groups.

treatment for the split-plot latin square is to provide two estimates of error for each experiment, one being for the comparison of varieties occurring in the same group and the other for varieties falling in different groups.

The relative efficiency ratios of 17 split-plot latin square experiments are given in Table 7. These efficiency ratios were calculated by the methods described by Bartlett (1) and Yates (17). The average standard errors for the 17 experiments were: 24.0 per cent for main plot error; 9.8 per cent for sub-plot error; 14.3 per cent for between group comparisons and 9.8 per cent for within group comparisons. The mean r values indicate that the sub-plot treatments averaged four times as accurate as the main plot treatments for the 4 × 4 squares and about five times as accurate for the 6 × 6 squares. The main plot comparisons were only two-fifths as efficient as in an ordinary randomized block arrangement but the latter was only two-thirds as efficient as the sub-plot comparisons, as shown by the mean r_m of 2.50 and r_s of 0.65, respectively. The split-plot latin square when used for varietal trials compared with randomized blocks was 35 per cent more efficient for within group comparisons but 6 per cent less efficient for between group comparisons. The results show that the split-plot latin square arrangement for varietal trials was decidedly superior to the ordinary randomized block arrangement. The study made by Yates in Rothamsted (17) showed that with plots split into two, there is usually a loss of accuracy even on the main plot comparisons owing to the transition from the latin square to a randomized block arrangement. In the case of a split into 4, there is little to choose on the main plot comparisons but a definite gain on the sub-plot comparisons.

The efficiency ratios of four split-plot randomized block experiments are given in Table 8. It is apparent that complete randomization would have reduced the efficiency of the sub-plot treatment, or varietal com-

Table 8.—Relative efficiency ratios of Split-plot randomized blocks

	r	r_m	r_s	r_b
	2.28	1.44	0.63	1.04
	12.37	2.00	0.16	1.08
	1.13	1.09	0.96	0.99
	1.42	1.18	0.83	1.01
Mean	4.30	1.43	0.64	1.03

Note.—Symbols as explained under Table 7.

parisons within groups to 64 per cent and only increased the efficiency of varietal comparison between groups by 3 per cent in the split-plot randomized block.

The studies by Yates (17) and Bartlett (1) showed relative efficiencies similar to those obtained in the Saskatoon tests, excepting that Bartlett, working with cotton in Egypt, found that complete randomization would have reduced the information on sub-plot comparisons to about 85 per cent as compared with 64 per cent obtained by the authors.

The semi-latin square was used in many Saskatchewan tests to afford a better distribution of varieties, where only 3 to 6 replicates are used, than is provided by the randomized block designs. The semi-latin square differs from the split-plot latin square in that in the latter each group of varieties is kept together in each replicate whereas in the former there is no such restriction. The efficiency of semi-latin squares compared with randomized block plan is summarized in Table 9. In this table the average percentage standard error of 133 experiments at Saskatoon, Bladworth and Tisdale are summarized by crops. The weighted mean for all crops was 14.8 per cent. The relative efficiency ratios show that the design was about as efficient as the randomized block. This similarity in precision to randomized blocks indicates that putting many varieties into each row and column results in loss in the efficiency of the double local control.

Lattice Designs

Lattice designs were proposed by Yates (18) in 1936 for the purpose of testing large numbers of varieties. During the period 1937 and 1946 a total of 81 lattices of various kinds were used in the Saskatoon and Tisdale tests. Summarized average percentage standard error per plot as obtained in these tests, together with the relative efficiency ratings of lattices compared with randomized blocks, are given in Table 10. The efficiency ratios were calculated by a method similar to that used by Yates (17) in comparing latin squares with randomized blocks.

As shown in Table 10 the triple lattices gave smaller mean standard errors than the simple lattices, the quadruple smaller than the triple, and the balanced smaller than the quadruple. This accords with expectation since the balanced arrangement, as shown by Yates (21), has greater precision than the other lattices for varietal comparisons. The higher standard error for the sextuple lattice and the smaller one for the rectangular

TABLE 9.—AVERAGE PERCENTAGE OF STANDARD ERRORS PER PLOT OF SEMI-LATIN-SQUARE EXPERIMENTS OF DIFFERENT CROPS

Crops	Wheat	Barley	Oats	Rye	Flax	Peas	Weighted mean
Average % S.E. per plot	14.64 (44)*	15.33 (45)	14.02 (39)	16.36 (3)	19.98 (1)	15.74 (1)	14.78 (133)
Relative efficiency†	93.8	101.8	91.4	98.2	55.3	—	97.8

† Efficiency relative to randomized blocks. * Numbers in brackets refer to number of tests.

TABLE 10.—AVERAGE PERCENTAGE STANDARD ERRORS PER PLOT OF VARIOUS KINDS OF LATTICES WITH DIFFERENT CROPS

Designs crops	Wheat	Barley	Oats	Flax	Weighted mean	Relative efficiency*
Simple lattices	10.38 (9)†	—	17.96 (1)	16.44 (5)	12.91 (15)	128.2
Triple lattices	12.54 (5)	11.28 (6)	9.95 (6)	12.89 (5)	11.57 (22)	159.7
Quadruple lattices	11.23 (4)	16.81 (1)	—	9.17 (2)	11.44 (7)	163.3
Sextuple lattices	13.74 (1)	—	—	—	13.74 (1)	113.2
Rectangular lattices	—	—	10.68 (1)	—	10.68 (1)	187.4
Balanced lattices	10.39 (10)	—	—	—	10.39 (10)	198.0
Lattice squares	13.24 (8)	12.70 (4)	13.04 (6)	11.24 (4)	12.72 (22)	132.1
Incomplete bl.	—	18.81 (1)	8.80 (2)	—	12.13 (3)	145.3
Weighted mean	11.48 (37)	12.84 (12)	11.51 (16)	13.12 (16)	12.01 (81)	148.2

* Efficiency relative to randomized blocks. † Numbers in brackets refer to number of tests.

lattice cannot be considered significant as there was only one experiment of each design. The lattice square design showed almost as high a mean standard error as the simple lattice.

The efficiency of the lattice designs is high compared with randomized blocks. The precision gains of the lattices over randomized blocks were 28 per cent for simple, 60 per cent for triple, 63 per cent for quadruple, 98 per cent for balanced lattices, 32 per cent for lattice squares and 45 per cent for balanced incomplete blocks. The average increased efficiency of lattices over randomized blocks was 48 per cent. In terms of replicates these increased efficiencies represent a saving of one replicate in five for simple lattices, 3 in 8 for both triple and quadruple lattices, 1 in 2 of balanced lattices, 1 in 4 of lattice squares and 2 in 3 of balanced incomplete blocks. The 126 randomized blocks in this study averaged 18.4 varieties per test whereas the lattices averaged 32.7 varieties per test. Since the greater the number of varieties in a test the larger the size of the standard error, even with the lattices, the randomized block is at an advantage in this respect, yet the lattices showed much higher efficiency in spite of that.

The efficiency ratings of the lattice designs in this study are in accord with those found by other workers. Yates (18, 23) using uniformity data without recovery of inter-block information found in two experiments gains of 26 per cent and 57 per cent over randomized blocks. Goulden (9)

TABLE 11.—AVERAGE PERCENTAGE STANDARD ERRORS PER PLOT OF SYSTEMATICALLY ARRANGED EXPERIMENTS IN TRIPLE ROD ROW PLOTS AND 1/40TH ACRE PLOTS

Crops	Wheat	Barley	Oats	Rye	Flax	Pea	Weighted mean
Rod-row plot-size	12.73 (11)	14.32 (6)	14.01 (5)	9.23 (3)	7.98 (1)	—	12.76 (26)
1/40th acre plot-size	7.85 (4)	6.03 (1)	4.46 (2)	4.63 (2)	10.08 (2)	9.48 (2)	7.28 (13)

from a study of 26 sets of uniformity data concluded that the incomplete block designs were 20 to 25 per cent more precise on the average than randomized blocks. Weiss and Cox (15) reported on two lattices of soy beans one giving an efficiency gain of 150 per cent and the other a loss of 31.5 per cent. Cochran *et al.* (4, 5, 6) studying designs in which inter-block information is recovered found substantial precision gains for the lattices, the range being from 0 per cent to 156 per cent. Cochran (5), studying the results of 93 lattices of corn in Iowa, found gains in precision amounting to a saving of two replicates in five when comparing triple lattices with randomized blocks. For lattice squares the savings compared with randomized blocks were as high as one replicate in three with 121 varieties tested. Zuber (24) using corn uniformity data found decided gains from the use of lattices. Bliss and Dearborn (2) reporting on 28 corn varietal trials of lattice squares in the New England States and Pennsylvania found gains in efficiency similar to those reported by Cochran and Zuber for Iowa. Wellhausen (16) studied the accuracy of incomplete blocks in 60 corn variety trials in West Virginia and found precision gains of 44 per cent; for 11 lattice squares, he found average gains of over 60 per cent and for 5 balanced lattices 14 per cent over randomized blocks. Johnson and Murphy (10) working with data from oat tests found lattice squares slightly superior in efficiency to triple lattices, and these in turn superior to simple lattices with gains of 2 to 55 per cent over randomized blocks. Torrie, Shands and Leith (14) studied data from 22 lattices of oats, barley and wheat and reported relatively little average gain in efficiency the average being between 5 and 10 per cent.

Systematic Arrangements

Systematically arranged field trials were carried on from 1925 to 1928 at Saskatoon using the common triple rod row plot described in Table 1 as E Class and the ordinary 1/40 acre plot. The 1/40 acre plot has a harvested area approximately 65 times as large as that of the E plot. The average percentage standard errors per plot for different crops are shown in Table 11 for the 39 tests having these two plot sizes. The results show that the standard errors were reduced effectively by the increase in plot size. The reduction was from 12.76 per cent for E plots to 7.28 per cent for 1/40 acre plots, a reduction of 43 per cent. While the errors from systematically arranged plots are not valid to use for a particular treatment comparison unless corrected on the basis of correlation, it is of interest to note that the standard errors are reasonable in magnitude.

TABLE 12.—NUMBER OF REPLICATIONS REQUIRED TO DETECT THE MINIMUM SIGNIFICANT DIFFERENCE IN PER CENT FOR DIFFERENT EXPERIMENTAL DESIGNS

Replication designs	3	4	5	6	7	8	9	10
R.B.	25.4	21.9	19.6	17.9	16.6	15.5	14.6	13.9
L.S.	20.8	18.0	16.0	14.7	13.6	12.7	12.0	11.4
Semi-L.S.	25.6	22.2	19.8	18.1	16.8	15.7	14.8	14.0
Simp. Latt.	22.4	19.4	17.3	15.9	14.7	13.7	12.9	12.2
Trip. Latt.	20.1	17.4	15.5	14.2	13.1	12.3	11.6	11.0
Quad. Latt.	19.8	17.2	15.3	14.0	13.0	12.1	11.4	10.9
Bal. Latt.	18.0	15.6	14.0	12.7	11.8	11.0	10.4	9.9
Latt. Sq.	22.0	19.1	17.0	15.6	14.4	13.5	12.7	12.1
Bal. In. Bl.	21.0	18.2	16.2	14.8	13.8	12.8	12.1	11.5

R.B. = Randomized Block; L.S. = Latin Square.
Semi-L.S. = Semi-Latin square; Simp. Latt. = Simple Lattice.
Trip.-Latt. = Triple Lattice; Quad. Latt. = Quadruple lattice.
Bal. Latt. = Balanced lattice; Latt. sq. = Lattice square.
Bal. In. Bl. = Balanced Incomplete Block.

Number of Replications for Different Designs

The number of replications required for field experiments depends on many factors such as the types of designs, variability of the testing materials, variability of the soil, number of varieties tested, available moisture in the soil, probable size of the varietal differences and also the accuracy of comparison required. If the probable size of the standard error per plot is known approximately from previous experiments, it is easy to determine the number of replicates needed to give statistical significance to a given magnitude of varietal difference. Thus if the standard error per plot from previous experiments averaged 10 per cent for randomized blocks, and five replicates are used, the standard error of a variety mean would be $10/\sqrt{5}$ or 4.4 per cent and a significant difference between varieties at the 5 per cent level would be approximately 3×4.4 or 13.2 per cent. As Cochran (3) pointed out, such a calculation is useful in avoiding experiments which from the start have little chance of showing relatively small varietal or treatment differences as significant.

Table 12 shows for each design used in the 521 tests of the present study, the minimum significant differences in per cent obtainable with different numbers of replicates from 3 to 10. Thus the number of replicates necessary at Saskatoon to obtain a 15 per cent difference significant at the 5 per cent level may be expected to be: 4 or 5 with balanced lattices, 5 or 6 with triple or quadruple lattices, 6 with latin squares and balanced incomplete blocks, 7 with simple lattices and lattice squares and 9 with randomized blocks and semi-latin squares. For a 10 per cent significant difference between varieties more than 10 replicates would appear to be needed for all designs excepting the balanced lattice.

DISCUSSION

As the present study included hundreds of experiments covering a period of 22 years, a first consideration was a scrutiny of all possible factors which might cause bias in the comparisons made. While these have been dealt with in earlier parts of this paper they merit some discussion here.

The various designs were not used to the same degree for the different crops as shown in Table 2. A comparison of the distributions of percentage standard errors in that table shows, for any particular design, relatively little variation between crops. For example, in the data on randomized blocks, the mean for each crop falls in the same class (12.1-16.0) as the mean for all of the tests. This factor, therefore, may be disregarded in assessing the comparative efficiencies of the designs. The site for each test was taken at random as far as its design was concerned; therefore the soil may be disregarded as a disturbing factor. A number of the tests were duplicates excepting for date of seeding. Examination of the data from such tests indicated clearly that date of seeding was not a disturbing factor in this study. The size and shape of the micro-plots varied within relatively narrow limits. Throughout the years choice of design was made quite independently of choice of type of micro-plot; consequently the type of plot was not a factor affecting the results. The effect of favourableness of season was to reduce the size of the percentage standard error (Table 4). However, with a large number of experiments covering a period of years, the means of the different designs are the most truly representative of the results in average seasons and therefore were used in the comparisons made. The number of varieties in a test was important in the comparisons of designs as shown in Table 5. The randomized block, with an average of 18.4 varieties per test was only 6 per cent as efficient as the latin square which averages 5.5 varieties. However, comparing latin squares with randomized block experiments having an approximately equal number of varieties (6.2) showed the latter design's efficiency to be 79 per cent. The effect of the number of varieties in a test was considered, therefore, throughout this study. Considering all of the possible biasing factors, the only one of importance appears to be number of varieties per test and this has been fully considered in the comparisons made.

The results of the study offer an overwhelming case in favour of the use of lattice designs under conditions such as obtained in the tests considered. Latin squares proved efficient but the limitation of this design to very few varieties made it unsatisfactory for testing large numbers of varieties. The randomized blocks were definitely inferior to the lattice designs as indicated by the efficiency ratios. The semi-latin squares not only averaged high in percentage standard error per plot but also had the added disadvantage of the bias in the estimation of error.

The lattices also were definitely superior to the split-plot latin squares and to the split-plot randomized blocks. The split-plot type of design proved to be the closest approach to lattices in one respect, viz., varietal comparisons within groups. However, comparisons between groups which constitute the majority of comparisons between pairs of varieties were low in precision.

The study of 1/40 acre and rod row results for 1925 to 1928 (Table 11) showed the large plots to have a much smaller standard error per plot than the micro-plots. If, however, the number of replicates in the rod row tests was increased the standard error of a variety mean could be reduced to that of the 1/40 acre plots and the space occupied would still be only a

fraction of that required for the large plots. There are undoubted advantages in large plot tests but the cost and area involved usually limit the use of such tests to relatively few varieties.

SUMMARY

1. Randomized field experiments were commenced by the Field Husbandry Department of the University of Saskatchewan at Saskatoon, in 1927. During the 22-year period, 1925 to 1946, a total of 523 experiments of various types of design were conducted by the Department, with 483 at Saskatoon. The standard errors per plot in per cent were obtained for the different experiments and a study made to ascertain: (1) the average value of the standard error for each type of design used for the different crops; (2) the relative efficiency of these designs for field testing, and (3) the probable number of replicates required in the planning of future experiments.

2. Randomized blocks (126 tests) showed an average standard error per plot of 14.6 per cent compared with 12.0 per cent for latin squares (123 tests). The average efficiency of randomized blocks was 67 per cent that of the latin squares. However, the randomized blocks had an average of 18.4 varieties per test whereas the latin squares averaged only 5.5 varieties per test. With an approximately equal number of varieties per test, the average efficiency of randomized blocks was thus raised to 79 per cent of that of the latin squares.

3. The average standard error per plot for 17 split-plot latin squares was 23.9 per cent for the main plot treatments and 9.8 per cent for the sub-plot treatments. The average standard error for comparisons of varieties between groups was 14.3 per cent and for varieties within a group 9.8 per cent. The split-plot latin square, compared with randomized blocks, was 35 per cent more efficient for within group comparisons, but 6 per cent less efficient for between group comparisons.

4. Semi-latin squares (133 tests) gave an average standard error of 14.8 per cent and approximately the same efficiency as randomized blocks. The error bias of the semi-latin squares was recognized as a disadvantage.

5. Lattice designs (81 tests) gave an average standard error of 12.0 per cent with a range of 10.5 per cent for balanced lattices to 12.9 per cent for simple lattices. Relative efficiency tests showed that the lattices averaged about 48 per cent more efficient than randomized blocks.

6. Systematically arranged tests, 39 in all, were run in the years 1925-1928 using triple rod row plots and 1/40 acre plots. The average standard error for the rod row tests was 12.9 per cent and for the 1/40 acre plots 7.3 per cent.

7. A table showing significant varietal differences in per cent for different numbers of replicates with the different designs is given.

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NECTAR AND POLLEN PRODUCING PLANTS IN MANITOBA

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INTRODUCTION

For the past twenty-six years (1922-1947) a record has been kept of the many dates when various plants, of interest especially to the beekeeper, first came into bloom at The University of Manitoba, Winnipeg, Manitoba. Most of the dates used in compiling the information given in Table 1 have been obtained during the past twenty years, although a few were secured previous to 1928. Each year the date, when each species of plant first came into bloom, was recorded. As will be seen, observations were made more frequently for some plants than for others. In addition to the number of years that observations were made, the tabulation states the earliest first bloom recorded and the latest date on which first bloom was observed. It will be seen that the seasons vary greatly from year to year. In the last column of the table, all first blooming dates for each species of plant were averaged and the average date indicated. For example, observations have been made for eighteen years for hazel bloom. The earliest recorded date for hazel pollen for the eighteen years was April 13 and the latest date on which pollen was first observed during the eighteen years was May 3. All

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TABLE 1.—FIRST BLOOMING DATES FOR SOME PLANTS VISITED BY HONEY BEES AT WINNIPEG

Plant	Number years observations made	Earliest first bloom	Latest first bloom	Average date of first bloom
Hazel	18	April 13	May 3	April 23
Poplar	18	April 15	May 3	April 25
Elm	5	April 17	May 13	April 28
Willow	15	April 22	May 23	May 3
Boxelder	9	May 3	May 22	May 12
Dandelion	22	April 18	May 31	May 14
Plum	19	May 6	June 8	May 19
Red currant	3	May 15	May 26	May 20
Saskatoon	13	May 10	June 8	May 21
Apple	6	May 20	May 29	May 26
Chokecherry	13	May 24	June 13	May 31
Lilac	7	May 29	June 9	May 31
Caragana	9	May 20	June 16	May 31
Honeysuckle	5	May 25	June 16	June 3
White Dutch clover	11	June 9	July 2	June 17
Alfalfa	6	June 14	June 24	June 18
Wild Rose	3	June 18	June 23	June 20
Yellow sweet clover	9	June 14	July 2	June 21
Alsike	3	June 18	June 22	June 21
White sweet clover	6	June 22	July 13	June 28
Sowthistle	7	June 24	July 18	July 11
Basswood	6	July 14	July 25	July 18

TABLE 2.—MANITOBA PLANTS VISITED BY HONEY BEES 1926-1945

Plant	May		June		July		August		September		Totals
	1-15	16-31	1-15	16-30	1-15	16-31	1-15	16-31	1-15	16-30	
Anemone	18	—	—	—	—	—	—	—	—	—	18
Hazel	7	—	—	—	—	—	—	—	—	—	7
Boxelder	58	23	—	—	—	—	—	—	—	—	81
Elm	22	4	—	—	—	—	—	—	—	—	26
Poplar	33	2	—	—	—	—	—	—	—	—	35
Apple	2	26	15	—	—	—	—	—	—	—	43
Currant	2	20	8	—	—	—	—	—	—	—	30
Gooseberry	2	14	2	—	—	—	—	—	—	—	18
Oak	2	6	7	—	—	—	—	—	—	—	15
Pincherry	4	7	2	—	—	—	—	—	—	—	13
Plum	21	32	16	—	—	—	—	—	—	—	69
Russian almond	12	7	2	—	—	—	—	—	—	—	21
Spirea	6	9	2	—	—	—	—	—	—	—	17
Tulip	10	2	4	—	—	—	—	—	—	—	16
Fruit bloom*	16	57	39	13	—	—	—	—	—	—	125
Saskatoon	7	27	8	2	—	—	—	—	—	—	44
Willow	97	45	18	6	—	—	—	—	—	—	166
Dandelion	31	164	142	45	3	—	—	—	—	—	385
Lilac	—	14	12	—	—	—	—	—	—	—	26
Mountain ash	—	4	7	—	—	—	—	—	—	—	11
Caragana	—	36	35	15	—	—	—	—	—	—	86
Chokecherry	—	19	20	6	—	—	—	—	—	—	45
Honeysuckle	—	17	21	9	—	—	—	—	—	—	47
Strawberry	—	2	10	5	—	—	—	—	—	—	17
Vetch	—	3	3	3	—	—	—	—	—	—	9
Cranberry	—	—	6	2	—	—	—	—	—	—	8
Rose	—	—	5	12	5	—	—	—	—	—	22
Raspberry	—	—	4	15	13	3	—	—	—	—	35
Mustard	—	—	25	39	18	8	2	2	—	—	94
White Dutch clover	—	—	14	40	30	20	8	8	4	—	124
Alfalfa	—	—	7	33	51	56	54	48	22	12	283
White sweet clover	—	—	7	83	156	160	146	130	70	28	780
Yellow sweet clover	—	—	17	114	163	155	145	128	70	29	821
Snowberry	—	—	—	5	16	13	5	—	—	—	39
Alsike	—	—	—	7	4	6	4	2	—	—	23
Clovers*	—	—	—	24	38	35	34	33	18	9	191
Sowthistle	—	—	—	5	14	47	51	51	15	3	186
Red clover	—	—	—	—	2	5	—	—	—	—	7
Basswood	—	—	—	—	3	8	2	—	—	—	13
Fireweed	—	—	—	—	—	6	9	6	—	—	21
Goldenrod	—	—	—	—	—	7	24	42	33	11	117
Aster	—	—	—	—	—	—	15	33	30	8	86
Gumweed	—	—	—	—	—	—	2	3	2	2	9
Sunflower	—	—	—	—	—	—	—	3	2	—	5
	350	540	458	483	516	529	501	489	266	102	4234

* Specific plants were not named by reporters.

of the eighteen dates, sixteen of which are not shown in the table, were averaged together with the result that April 23 is the average date at Winnipeg on which we may expect hazel to begin shedding pollen. It will be seen by consulting the last column, that hazel is the first source of pollen here. The other plants named are listed in the order in which their average date of blooming occurs.

For twenty consecutive years certain beekeepers, widely separated in Manitoba, have kept daily scale colony records for the Department of Entomology for May, June, July, August and September. On the printed report forms used by these beekeepers, there is a place to record the names of plants on which honey bees are working during each half of each of these months. Through the years many of these selected beekeepers have observed and have made records of the plants on which their honey bees were working. It should be remembered that a record for the first half or the second half of any month does not indicate whether it was early or late during that half-month period when the flower was visited or whether the flowers were visited throughout the entire half-month period. All of the records secured have been brought together and arranged in Table 2 for the years 1926-1945 with the exception of those records of numerous less important plants which have been omitted from the tabulation. Each time a specific plant was named by a beekeeper as having been visited by honey bees during any half month, it was credited with one point. For example seven beekeepers during the period of twenty years mentioned that honey bees were working on white sweet clover during the first half of June and one hundred and sixty beekeepers said that, similarly, white sweet clover was visited by honey bees during the latter half of July. Table 2 indicates the wide variety of plants visited by honey bees in Manitoba and the relative time of the year that these plants are so visited.

Table 3 is a compilation of data showing the trend of sweet clover and alfalfa acreage, the growth of beekeeping, the variations in the price of honey and the rise and decline of the average production of honey per colony in Manitoba from 1921 to 1947.

TABLE 3.—CHANGES FROM 1921-1947 FOR MANITOBA IN THE ACREAGE DEVOTED TO SWEET CLOVER AND ALFALFA AS WELL AS IN THE NUMBER OF BEEKEEPERS, NUMBER OF COLONIES OF HONEY BEES, AVERAGE PRICE OF HONEY AND THE AVERAGE YIELD OF HONEY PER COLONY

Five-year periods	1. Average yearly acreage of sweet clover	1. Average yearly acreage of alfalfa	2. Average number of beekeepers per year	2. Average number of colonies per year	2. Average price of honey per pound	2. Average yield of honey per year
					cents	lb.
1921-1924*	71,070	6,391	833	10,197	18.0	86
1925-1929	169,195	9,832	1,822	26,770	13.6	102
1930-1934	299,817	19,061	2,358	35,364	7.8	133
1935-1939	296,972	41,240	3,378	54,514	7.0	127
1940-1944	195,260	178,800	2,960	48,278	11.8	89
1945-1947**	122,000	221,333	4,533	65,000	20.3	76

* Four-year period. ** Three-year period.
1. Manitoba Dept. of Agr. Statistics.
2. Dominion Dept. of Agr. Statistics.

DISCUSSION

At Winnipeg, as will be seen in Table 1, our first source of pollen is from hazel. Poplar follows almost at once, but as it comes into bloom and sheds its pollen quickly, it is usually a fleeting source for honey bees. Furthermore, it may be windy during the period of pollen shedding and then the pollen grains are carried away from the staminate flowers as soon as they are ripe and, therefore, are not available to the honey bees for any length of time. The wind may also be too strong for honey bees to fly during the time that it is being shed. Although elm and boxelder are visited on occasion by honey bees, the staminate flowers of these trees are often destroyed by frost when they are about to shed pollen. Willow follows fairly quickly after the early pollen-producing plants and is the main source of pollen for building up colonies. Honey bees could always find pollen before it was observed on the plants. The pollens from hazel and poplar are gray, while willow pollen is yellow. Usually within three or four days after gray pollen was being brought in, yellow pollen made its appearance on the legs of the worker honey bees. We have observed honey bees on staminate flowers only, of boxelder. Dandelion is a most important plant for beekeepers. It is a source of both pollen and nectar, is widespread in its distribution, and blooms in abundance over a period of several weeks. The total destruction of dandelions would be a disastrous event for beekeepers. Many of the plants which follow in the list in Table 1 are of minor importance, but, taken together, along with some others not mentioned, they help to carry the honey bees through the period when brood rearing is the main occupation in the colony. At the end of the dandelion flow, which occurs about the end of the first week of June, there is a dearth of available nectar (1) which lasts for from one to two weeks. During this period in many areas it may be advisable to feed sugar syrup in order that brood rearing may not be interrupted. This is particularly true if colonies are low in stores at the end of the dandelion flow, due to rapid consumption of food.

The main sources of surplus honey are the legumes which begin to bloom early in the second half of June as indicated in Table 1. Honey bees make surplus honey also from sowthistle nectar which becomes available early in July.

In Table 2, anemone and hazel yielded pollen during the first half of May. Boxelder, elm and poplar yielded pollen throughout May. Such plants as anemone, hazel, and poplar yield pollen during the latter part of April, although the tabulation does not show this. Beekeepers were not asked to report on any plant visited by honey bees earlier than May 1. The next nine plants listed come into bloom in May and in some years continued to bloom in early June. Saskatoon bloom is most common during the last half of May. Willow was widely recognized as an important pollen-bearing plant, especially in May. The importance of dandelion is recognized by the many references to it, especially during the last half of May and the first part of June. Caragana, which is used widely for hedges for homes and near roads to halt the movement of snow, is assuming increasing importance to the beekeeper. The next seven plants are of relatively little importance. Mustard abounds in many fields, but soon may be much

less common if farmers make continued increasing use of weed killers. Yellow sweet clover, white sweet clover, alfalfa and white Dutch clover are our most important main crop nectar-producing plants in Manitoba (1), the first two being especially important. Their season is prolonged from the last half of June through July and August and into the first half of September where these plants are pastured. Unfortunately the sweet clovers are not as popular as they were some years ago. Sweet clover weevil has been very destructive to seedlings in early summer and whole fields have been destroyed shortly after the seedlings emerged from the ground. Then, too, many farmers cut the crop for hay in the early bloom stage, plow immediately and keep the land fallow for the remainder of the season. This is recommended practice in the sub-humid areas because it not only improves the quality of the hay, but also prevents the severe drain upon soil moisture that is occasioned by an advanced crop or a second crop of sweet clover. Some fields of sweet clover are grown for seed and these provide excellent honey bee pasture over a long season. Alfalfa is gaining in popularity, but when it is cut for hay in the early blooming period, it provides little nectar. The frequent failure of alfalfa to set seed in quantity has the effect of inducing farmers, who would prefer to produce seed rather than hay, to cut the crop for hay, instead of taking the chance of realizing a poor crop of seed. This practice of course, makes less bloom available for the honey bees. The honey bees themselves are not as co-operative as they might be in this regard. Sowthistle has increased in abundance since the 1930's when grasshoppers held it in check. Weed-killers again may reduce this source of nectar. Fireweed is restricted to the wooded areas of Manitoba. Goldenrod and aster are not important sources of nectar in Manitoba as is demonstrated by the fact that we now get practically no surplus honey (1) after the middle of August.

As mentioned previously sweet clovers are not grown as extensively now as they were ten or fifteen years ago. This decrease in acreage is shown in Table 3. From a yearly average of nearly three hundred thousand acres during the ten-year period beginning 1930 it has declined to a yearly average of one hundred and twenty-two thousand acres during the past three years. This has coincided with a reduction in the average production of honey per colony from 133 pounds per year for the period 1930-1934, to 76 pounds for the three-year period 1945-1947. The alfalfa acreage in Manitoba has increased greatly during the past eight years, but this has not compensated for the decrease in the sweet clover acreage as most of the alfalfa is cut for hay before it has been many days in bloom. Formerly, when sweet clover was cut for hay, much of the acreage was subsequently pastured and this practice permitted new bloom to appear in the field throughout the summer. Furthermore, much sweet clover was grown for seed. Alfalfa could at least partially replace sweet clover as a honey crop if a much larger acreage produced seed. The total production of honey in Manitoba has been well maintained through the years, however, since more people have become interested in beekeeping.

As honey bees are of much more value to agriculture as pollinators than they are as honey producers, it is most important that the honey bee population be maintained or, better still, increased. During the past few years the price of honey has been high enough to encourage beginners and

to produce apiary extensions. At the end of World War 1 in 1918, the average price of honey per pound was 30 cents. Thirteen years later (1931) the price had dropped to 7 cents a pound for the beekeepers of Manitoba New nectar-producing plants are needed on Manitoba farms to stimulate beekeeping activity. The growing of more alfalfa for seed would be of assistance or an increase in the acreage of sweet clover grown for seed would help to make more honey bees available for general pollination purposes. Better yields of honey would also be secured.

SUMMARY

1. First available pollen is from anemone, hazel and poplar. In an average year, first pollen is being gathered by honey bees by April 23.

2. Elm, willow, boxelder, dandelion and fruit bloom follow in succession and provide pollen and nectar in the ensuing weeks. Dandelion provides both pollen and nectar in abundance and is most important to the beekeeper.

3. The clovers and alfalfa are the main sources of surplus nectar in Manitoba. Sweet clovers are not grown as extensively as in former years and frequently the acreages now used for sweet clover are not managed to the best advantage for the beekeeper.

4. Mustard and sowthistle, both sources of surplus nectar, now face an uncertain future if weed-killers continue to be used more extensively.

5. New nectar-producing plants to be grown widely on Manitoba farms are needed badly if this province is to continue to hold its place among the leading honey producing provinces of Canada.

ACKNOWLEDGMENTS

The author is indebted to the many beekeepers who kept records of dates when their honey bees visited nectar-and pollen-producing flowers as shown in Table 1.

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